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Integration of summer and fall cover crops in vegetable cropping systems

Raymond Albert Kruse
Iowa State University

Integration of summer and fall cover crops in vegetable cropping systems

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Raymond Albert Kruse

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Program of Study Committee:
Ajay Nair, Major Professor
Denny Schrock
Micheal Owen
Rajeev Arora

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Dedication

I would like to dedicate this work to my parents Gary and Karen Kruse. Ever since I was a little kid they have helped me become my best. From 4-H projects in high school, to entrepreneurial ideas, and supporting me through college, they have always been there for me. They also taught me that while I grow with my passion that I can share that growth with others to help them become their best as well.

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ABSTRACT

The demand for locally produced vegetables is growing in the Midwest, including Iowa. However, vegetables are a small fraction of total cropland in the state, and little research exists on approaches and techniques to increase the sustainability of vegetable production systems. Including cover crops in vegetable crop rotations can contribute to sustainability in vegetable cropping systems. This research investigated the integration of summer and fall cover crops in vegetable cropping systems to reduce weeds and nutrient leaching, improve soil chemical and biological properties, and enhance crop growth, yield, and produce quality. Cover crops studied in this research included buckwheat (*Fagopyrum esculentum*), cereal rye (*Secale cereal*), cowpea (*Vigna unguiculata*), crimson clover (*Trifolium incarnatum*), black oats (*Avena strigosa*), oilseed radish (*Raphanus sativus* var. *oleifera*), and sorghum-sudangrass (*Sorghum bicolor ssp. drummondii*). Effects of these cover crops were tested on fall production of cabbage (*Brassica oleracea* 'Caraflex') and lettuce (*Lactuca sativa* 'Adriana') and spring production of potato (*Solanum tuberosum* 'Yukon Gold' and 'Red Pontiac').

In vegetable cropping systems, weeds have been traditionally managed through tillage or chemicals. With growing awareness and demand for sustainably grown produce, growers are interested in using weed control strategies that could provide environmental benefits. Two of the studies conducted as part of this research investigated effects of four cover crops (buckwheat, cowpea, black oats, and sorghum-sudangrass) on fall cabbage and lettuce production. Both studies were a split-plot randomized complete block design with cover crops as the whole plot and planting date of the vegetable as the subplot factor. Two planting dates were tested (immediately after or eight days after

cover crop soil incorporation). The third study investigated the effect of fall planted cover crops (cereal rye, crimson clover, and oilseed radish) on soil nutrient concentrations, weed populations and growth, yield and quality of the successive spring potato crop. The study was a Latin square split-plot design with cover crop as the whole plot and potato cultivars as the subplot factor. All three studies included a no cover crop plot as a control treatment.

The first two studies clearly showed that cover crops can be used to help manage weeds during the summer time before planting of a fall vegetable crop. Cover crop biomass was highest for sorghum-sudangrass. Cowpea cover crop produced the lowest biomass. Buckwheat was the best cover crop at suppressing weeds while cowpea did not provide sufficient weed suppression. All cover crops did suppress weeds compared to the control. In the cabbage study, cowpea had a positive effect on soil nitrate concentration and produced the highest marketable cabbage yields (10,654 and 7,838 $kg \cdot ha^{-1}$ in 2013 and 2014, respectively). Between the two planting times, early planting (immediately after cover crop soil incorporation) seemed to benefit cabbage yield only in the cowpea treatment. Results in the lettuce study were very similar. Cowpea shortened the time to harvest for the lettuce crop. The decrease in days to maturity was a minimum of 5 d in 2013 to 13 d in 2014. The early planting also showed evidence in decreasing the days to maturity. In 2014 planting immediately after soil incorporation of buckwheat and the control treatments, decreased the days to maturity of the lettuce crop than those planted eight days after soil incorporation of the buckwheat and control treatments.

The third study with fall planted cover crops, examined how cover crops influenced soil nitrogen, weeds and yield of the following potato crop. Positive effects were seen from the cover crops on increasing soil nitrogen and decreasing weed populations but, the advantages were short lived. These advantages did not result in a crop yield increase or decrease in the following potato crop. All three experiments demonstrate that cover crops can be incorporated into vegetable production systems on Iowa's landscape to provide environmental benefit without negatively affecting yield.

CHAPTER 1. GENERAL INTRODUCTION

Vegetable crops in the Midwest are generally considered short season crops. Normally these crops do not occupy the entire growing season in the field as opposed to most grain crops like corn (*Zea mays*). Vegetable growers growing a spring and fall vegetable crop often have a fallow period of 30 to 45 days between the summer harvest of the spring crop and planting of fall crop. This allows a window in the growing season where weeds, if not properly managed, could take up soil nutrients, produce seeds, and add to the weed seed bank in the soil. Growers either manage weeds through herbicides or tillage. Herbicides have advantages in terms of low cost, ease of application, and in most cases, no disturbance to the soil. But, there are challenges with the use of herbicides such as, the evolution of herbicide-resistant weeds (Chatham et al., 2015), worker protection requirements (FMC Corporation, 2015; Syngenta Crop Protection LLC., 2015), and isolation requirements to avoid herbicide drift to non-target areas (FMC Corporation, 2015). In addition there are plant back period requirements for some crops after certain herbicide applications (BASF Corporation, 2010; FMC Corporation, 2015; Syngenta Crop Protection LLC., 2015).

An alternative to herbicides is tillage. Even though tillage can bypass issues related to herbicide usage it does not come without its drawbacks. Kibet et al. (2016) found low soil organic carbon and mean weight and diameter of water-stable aggregates with intensive tillage as compared to less intensive tillage practices. Intense tillage has also been associated with decreased soil water content. Gozubuyuk et al. (2015) reported decreased soil water content in upper layers of cropland soil in intense tillage treatments compared to no tillage treatments. It is also universally agreed on that intensive soil tillage results in exposed soil that is vulnerable to weather degradation processes from wind and water.

Mowing is another option for weed control. This method has the advantage of being able to control weeds without chemicals and does not impact soil thus lessening erosion potential. This type of weed control also has the advantage of not churning the soil to control weed growth since the mower just passes over the soil surface without disturbing the soil. The drawback with mowing is that this low intensity form of weed control does not control weeds as intensely as needed for agricultural production. Ringselle et al. (2015) found that fall mowing of weeds after a cereal crop inconsistently reduced weed shoot density and also noted that better weed control could be attained with tillage or herbicides.

Recently the use of cover crops is receiving renewed interest for sustainably managing weeds. A cover crop is a crop that is not intended for harvest and is managed to maintain and improve soil fertility, water quality, and help manage weeds, insects, and diseases (Nair et al., 2015). Cover crops often are planted after harvesting a vegetable crop and then terminated before the planting of the next vegetable crop. There also are production systems where cover crops are used as living mulch, growing at the same time as the vegetable crop. Weed suppression through cover crops has been clearly demonstrated. Studies by Bjoerkman et al. (2015); O'Reilly et al. (2011): Wiggins et al. (2015) have reported positive measures of weed control with the use of cover crops during fallow periods. Cover crops also reduce weed pressure in successive crops after cover crop soil incorporation (Korres and Norsworthy, 2015). Cover crops provide many other benefits in addition to weed control. Fibrous rooted cover crops can reduce soil erosion (Corak et al., 1991; De Baets et al., 2011) as well as improve soil aggregate stability (Hermawan and Bomke, 1997). An additional advantage of using cover crops is the increase in soil organic matter. Ding et al. (2006) reported increased soil organic matter when using cover crops as opposed to no cover crop. This is an important factor to consider because soil organic matter can be associated with soil productivity (Ding et al., 2006). In the wake of issues related to nutrient leaching and contamination of ground and surface water in modern day agriculture, cover crops can play a significant role in reducing nutrient leaching by storing residual nitrogen in the fall. Wyland et al. (1996) reported reduced nitrate leaching in vegetable production systems with cover crops.

A large concern for growers looking to adopt the use of cover crops is how the cover crop will affect the cash crop yield. Many studies have shown the benefits of cover crops in vegetable cropping systems. For example, improved onion (*Allium cepa*) yield was reported when an oilseed radish (*Raphanus sativus* var. *oleifera*) cover crop preceded the onion crop (Wang et al., 2008b). Similar results were seen in a lettuce (*Lactuca* sativa) crop planted after a cowpea (*Vigna unguiculata*) cover crop (Wang et al. 2008a).

In addition to identifying and establishing a suitable cover crop, another factor to consider is the planting date of the vegetable crop soon after termination of the cover crop. Ackroyd and Ngouajio (2011) suggested that planting too soon after cover crop termination decreased muskmelon yield (*Cucumis melo*) when using oilseed radish, oriental mustard (*Brassica juncea*), and yellow mustard (*Sinapis alba*). Certain cover crops have also been shown to decrease vegetable yield. Finney et al. (2009) observed decreased fall cabbage yields when using a sorghum-sudangrass cover crop. Reductions in average head weight were 0.2 to 0.3 kg per head (Finney et al., 2009). Negative impacts of cover crops on soil nitrogen availability have also been reported. Kuo and Sainju (1998) observed that cereal rye (*Secale cereale*) and annual ryegrass (*Lolium multiflorium*) decreased the availability of inorganic nitrogen when incorporated into the soil while hairy vetch (*Vicia villosa*) can increase the available nitrogen.

Much of the research focusing on cover crops in Iowa has been conducted in row crops. What is not well understood is how cover crops can influence vegetable crop production in Iowa. There are obvious reasons as to why this void in research exists. In Iowa there are only 7,724 acres of commercial vegetable production (U.S. Department of Agriculture, 2014) but research is needed about the integration of cover crops in Iowa vegetable production. According to the Leopold Center for Sustainable Agriculture (2012) and Lucht (2015) the demand for locally grown food is growing in Iowa. Even at a national scale, local foods have had an increase in demand (Doering, 2015). More research in needed to study effects of cover crops on soil properties and environmental aspects such as nitrogen leaching, and crop growth, development, and yield. Within the U.S. a number of studies have been conducted in states such as California (Wang et al., 2008a; Wyland et al., 1996), Michigan (Wang et al., 2008b), New York (Bjoerkman et al., 2015), and North Carolina (Finney et al., 2009), on cover crops for vegetable crop systems. Locations outside U.S. have also been investigating the effects of cover crops on following vegetable crops such as Australia (Little et al., 2004) and Italy (Campiglia et al., 2009). Although these studies provide valuable information on benefits of cover crops in vegetable systems, more research is needed on cover crops under Iowa growing conditions. Most Iowa vegetable growers are small scale and operate locally catering to farmers markets, farm stands, and other direct consumer markets. Most vegetable growers in Iowa look to use sustainable crop production tools that can include cover crops, to keep their production system sustainable. These growers need timely, relevant, and research-based information on cover crops that can be used in their vegetable production systems.

The primary objective of this project was to investigate the use of cover crops and quantify their effects on various soil and crop parameters under Iowa growing conditions. Chapter two of this thesis reports the effect of summer planted cover crops (buckwheat [*Fagopyrum esculentum*], cowpea [*Vigna unguiculata*], black oats [*Avena strigosa*], and sorghum-sudangrass [*Sorghum bicolor ssp. drummondii*]) on fall cabbage production. The study also suggests a suitable planting date for cabbage after termination of the cover crops. Chapter three discusses a similar focus on cover crops and investigates on their affect on fall lettuce production. Chapter four describes the effects of fall planted cover crops (cereal rye, crimson clover [*Trifolium incarnatum*], and oilseed radish) on spring potato (Solanum tuberosum) production. The final chapter summarizes these studies and lists potential issues that need further investigation for cover crop use in vegetable production systems in Iowa.

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CHAPER 2. SUMMER COVER CROPS AND PLANTING DATE INFLUENCE SOIL NITRATE CONCENTRATION AND CABBAGE YIELD

Modified from a paper written for HortTechnology

Raymond Kruse[1] and Ajay Nair[1*]

Abstract

Vegetable fields in the Midwest often have a summer fallow period between spring and fall vegetable crops. Common practices among growers to manage weeds during the summer fallow include herbicides or tillage, both could negatively affect the environment. A sustainable option to manage weeds during the fallow period is to grow cover crops. This study investigated effects of four cover crops, buckwheat (*Fagopyrum esculentum* Moench. 'Mancan'), cowpea [*Vigna unguiculata* (L.) Walp. 'Iron & Clay'], black black oats (Avena strigosa Schreb. 'Black Oats'), and sorghum-sudangrass [*Sorghum bicolor* (L.) Moench ssp. *drummondii* (Nees ex Steud.) de Wet & Harlan 'Grazex II'] on production of fall cabbage (*Brassica oleracea* L. var. *capitata* 'Caraflex'). The study was a split-plot randomized complete block design with cover crops as the whole plot and cabbage planting date as the split-plot factor. Two planting dates were tested (immediately after or eight days after cover crop soil incorporation). Above ground cover crop biomass ranged from 3.0 $Mg{\cdot}ha^{-1}$ in cowpea to 5.4 $Mg{\cdot}ha^{-1}$ in sorghum-sudangrass in 2013. In 2014, above ground biomass ranged from 1.2

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[1]Department of Horticulture, Iowa State University, Ames IA 50010

*To whom correspondence should be addressed; E-mail: nairajay@iastate.edu

$Mg \cdot ha^{-1}$ in cowpea to 2.6 $Mg \cdot ha^{-1}$ in sorghum-sudangrass in 2014. Results show that cowpea had a positive effect on soil nitrate concentration and produced the highest marketable cabbage yields (10,700 and 8,400 $kg \cdot ha^{-1}$ in 2013 and 2014, respectively).

No differences in soil microbial biomass were seen among any of the treatments. Chlorophyll content varied between the treatments in 2013 only with cowpea having some of the highest values. Among the other cover crops sorghum-sudangrass showed detrimental effects on yield while the other cover crops did not affect cabbage yield.

Introduction

Many direct market Midwest vegetable growers diversify their produce offerings during the spring, summer, and fall growing seasons. Some of the crops used to diversify produce offerings include short-term cool-season crops in the spring and fall. There is often a short fallow period in the hot summer season between the spring and fall crops. This short period is not long enough to grow a third vegetable crop between the seasons. Growers actively manage weeds in these fallow periods with herbicides or mechanical cultivation. With the current interest in sustainable production practices among growers, there are possibilities of incorporating short duration summer cover crops during the fallow period. In addition to providing weed suppression (Kumar et al., 2009; Bugg and Dutcher, 1989), cover crops can add organic matter (Ding et al., 2006), reduce soil erosion (Corak et al., 1991), and reduce nutrient leaching (Kaspar et al., 2012)

Cover crop biomass is one way to measure the effectiveness of the planted cover crop (Morton et al., 2006). Prior research has shown that an increase in grass cover crop biomass resulted in decreased weed biomass per unit area (Creamer and Baldwin, 2000).

However with the increase in cover crop biomass, the concern increases about the carbon to nitrogen ratio in the cover crop biomass and soil once the cover crop is terminated and incorporated (Kuo et al., 1997). With a high carbon to nitrogen ratio in the cover crop biomass, the risk of nitrogen immobilization is increased (Parr et al. 2014), preventing the following cash crop from obtaining nitrogen. This raises the question of which cover crop is best for biomass production while not hindering the following vegetable crop.

There are a number of cover crops that efficiently grow in warm conditions, generate sufficient biomass, and thus smother weeds. Cowpea, a warm season, legume cover crop, has been shown to generate a high amount of biomass as well as fix nitrogen (Creamer and Baldwin, 2000). With the capability to fix nitrogen in the soil, concerns about nitrogen immobilization are reduced since more nitrogen is available in the soil. Cowpea biomass has a low carbon to nitrogen ratio relative to many other cover crop species (Creamer and Baldwin, 2000) further reducing concerns about nitrogen immobilization. Cowpea is not a common crop in Midwest vegetable cropping systems, but we suggest that given its quick growing and nitrogen fixing attributes it has the potential as a useful cover crop in this region. Another short-term cover crop option for growers is buckwheat. Buckwheat has a reputation for suppressing weeds due to its early season competitive growth (Brust et al., 2014). Even though it is a cool-season crop, buckwheat best suppresses weeds and generates biomass during warm weather (Björkman and Shail, 2013). Buckwheat has the same carbon to nitrogen ratio as cowpea (Creamer and Baldwin, 2000) but lacks the ability to fix nitrogen.

In the grass family a well suited cover crop for warm weather planting is sorghum-sudangrass. This annual grass cover crop has proven to out compete other warm season annual grasses such as millets and sorghum in above ground biomass, however, the crop has a high carbon to nitrogen ratio (Creamer and Baldwin, 2000). This is undesirable due to the nitrogen immobilization in soil that can adversely affect growth and yield of the successive vegetable crop. Another short duration cover crop that can be planted in the Midwest is black oats. Previous research has shown that common oat (*Avena sativa* L.) biomass has averaged 660 $kg \cdot ha^{-1}$ with a maximum of 1,070 $kg \cdot ha^{-1}$ achieved when seeded as a fall cover crop (Johnson et al., 1998). Higher amounts of biomass have been achieved with black oats (*Avena strigosa* Schreb.) in southern states with maximum of 5,452 $kg \cdot ha^{-1}$ (Agriculture Research Service, 2005) when sown as a winter cover crop. With the ability of black oats to perform in previous studies as a winter cover crop combined with it's short growing season, uncertainty exists of black oats ability to accumulate biomass during the short warm season of this study. One of the reasons of adding black oats (*Avena strigosa* Schreb.) to this study is the familiarity of growers with it's close relative common oat (*Avena sativa* L.)

Little research has been done regarding the planting date of vegetable transplants after a cover crop has been terminated (Ngouajio, 2011) especially with the cover crops selected for this study. One reason to consider this parameter is the presence of allelotoxins from the cover crops. Yield loss attributed to allelotoxins has been demonstrated with spring seeded brassica cover crops in muskmelon (*Cucumis melo* L.) if the planting date was too short (Ackroyd and Ngouajio, 2011). A planting date of two weeks is suggested for cover crops such as cereal rye (*Secale Cereale*) and ones in the brassica family (Ngouajio, 2011). Due to the limited season, observing a two week planting date in the Midwest would limit the growing time for the successive vegetable crop in the fall. In our study to better relate to Midwest vegetable grower practices, the transplanting times of the vegetable crop was either immediately or eight days after cover crop soil incorporation.

The scope of this research was to assess the effect of short duration warm season cover crops as well as transplanting date on growth, yield, and quality of fall planted cabbage. Soil chemical and biological parameters were also measured to provide further insight on environmental benefits cover crops could provide.

Materials and Methods

Site description

This study was conducted in 2013 and 2014 at the Iowa State University Horticulture Research Station (42.10660 latitude and -93.58890 longitude at 300 m. above sea level). The field historically was artificially modified as a putting green research plot more than 10 years ago. The top 41 to 51 cm of soil was modified and had a 68% sand, 20% silt and 12% clay content. Below the modified layer was a Clarion soil, fine-loamy, Typic Hapludoll, with a 2% to 6% slope. At the beginning of the 2013 growing season soil pH, EC, and cation exchange capacity were 5.1, 0.10 mS/m, 0.095 meq/g, respectively. Predominant weeds included common lambsquarter (*Chenopodium album* L.), green foxtail [*Setaria viridis* (L.) P. Beauv.], greenflower pepper weed (*Lepidium densiflorum* Schrad.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.), prickly lettuce (*Lactuca serriola* L.), shepherdspurse [*Capsella bursa-pastoris* (L.) Medik.], and yellow foxtail [*Setaria pumila* (Poir.) Roem. & Schult.].

Experimental design

The study was arranged as a split-plot randomized complete block with four replications. The whole plot consisted of cover crop treatments with a plot size of 7.3 × 7.8 m. Cover crops included buckwheat, cowpea, black oats, and sorghum-sudangrass. The control treatment of no cover crop was included. In 2014, 'Nutri-Plus' sorghum-sudangrass was used instead of 'Grazex II'. Each whole plot was split in half and assigned to a subplot treatment, one of two planting dates of cabbage after cover crop soil incorporation. The first planting date was immediately after cover crop soil incorporation. The second planting date was 8 d after cover crop soil incorporation. For the remainder of this paper, specific combinations of cover crop treatments and planting dates will be referred to by "cover crop" followed by "planting date". For example "cowpea-early" with cowpea defining the cover crop and early defining the planting date immediately after cover crop soil incorporation.

Cover crop growth

Cover crops were seeded on 2 June and 12 June in 2013 and 2014, respectively, with the exception of sorghum-sudangrass in 2014 which was planted on 16 June. Soil preparation was done using a roto-tiller to a depth of 11 to 15 cm. Cover crops were seeded using a 107 cm wide variable rate Gandy drop spreader (Anertec & Gandy Co., Owatonna, MN) that was calibrated to seed buckwheat, cowpea, black oats, and sorghum-sudangrass at the rate of 55, 93, 67, and 55 $kg \cdot ha^{-1}$, respectively. After seeding, the soil was roto-tilled to a depth of 5 cm to incorporate seeds. Cover crop aboveground biomass in 2013 was determined at 63 d after planting on 4 Aug. In 2014, cover crop aboveground biomass was determined on 4 Aug., 53 d after cover crop planting. Cover crop biomass samples were taken using two 50 × 50 cm quadrats. Sampling was done by cutting plants approximately 1 cm above the ground level using shears. Cover crops were separated from weed biomass and dried in a forced air oven for 3 d at 67°C until the biomass had reached a constant weight. Cover crops were terminated using a Rhino ORC 10 flail mower (Rhino, Gibson City, IL). The shredded cover crop residue was roto tilled into the soil to a depth of 20 to 25 cm.

Transplant production

Transplants were started respective to their intended transplant date for each subplot in 98-cell flats. Cabbage seeds (Johnny's Selected Seeds, Winslow ME) were sown on 10 and 19 June in 2013, and 30 June and 8 July in 2014, into a growing mix of 85% LC1 soilless potting mix (Sun Gro Horticulture Canada Ltd, Seba Beach, AB, Canada) and 15% compost in 98-cell plug trays. Seedlings were fertigated weekly with a combination of two water soluble fertilizers (21N-2.2P-16.6K and 15N-2.2P-12.45K-4Ca-2Mg) (J.R. Peters, Inc., Allentown, PA). In both years, transplants were moved out of the greenhouse to harden off for 7 d before transplanting in the field.

Transplanting and establishment

A Nolt's RB448 (Nolt's Produce Supplies, Leola, PA) raised bed mulch layer was used to construct the beds with a plastic mulch cover. Beds were 0.61 m wide and 1.83 m apart center to center. Drip tape installed underneath the plastic mulch had a flow rate of 0.83 l/min per 30.5 m. Transplants were planted using a Rain-Flo 1600 Series II water wheel transplanter (Rain-Flo Irrigation LLC., East Earl, PA). Transplanting of the early cabbage was done (immediately after cover crop soil incorporation) on, 6 Aug. and 5 Aug. in 2013 and 2014, respectively. Transplanting of the late planted cabbage was done (8 d after cover crop soil incorporation) on 14 Aug. and 13 Aug. in 2013 and 2014, respectively. Transplants were planted in two rows on each bed that were 23 cm apart. Within each row, plants were spaced 30.5 cm apart and staggered with the adjacent row.

Fertigation

Fertigation started the second week after transplanting in 2013 and the first week after transplanting in 2014. A DosmaticPlus (Hydro Systems Company, Cincinatti, OH) inline volumetric flow injector was used to fertigate the crop. The fertilizer concentrate was calculated so that the final concentration of N applied was 100 $mg \cdot kg^{-1}$. The fertilizer used was 21N–2.2P–16.6–K (J.R. Peters, Inc., Allentown, PA) and was applied over 3 consecutive weeks to apply 81, 19, and 76 $kg \cdot ha^{-1}$ of N, P, and K, respectively.

Soil nitrate leachate

Lysimeters (Model 1900, Soil Moisture Corp., Santa Barbara, CA) were installed in the late planted cabbage plots to estimate nitrate nitrogen leaching 61 cm. below the soil surface. Installation followed the protocol for overall critical soil water sampling with silica slurry (Soil Moisture Corp., Santa Barbara, CA) on 19 Aug. and 14 Aug. in 2013 and 2014, respectively. Leachate was sampled beginning 29 Aug. and 20 Aug. in 2013 and 2014, respectively. Collection continued weekly after the starting date for a total of eight consecutive weeks with 40 ml of sample collected per time from each lysimeter. Samples were analyzed for nitrate concentration using a Lachat QuikChem 8500 Series 2 (Hach Company, Loveland, CO) flow injection analyzer.

Plant health score

After transplanting, plant health was rated on a five point integer scale. In 2013 health ratings were done on 22 and 29 Aug 2013 and on 15 Aug. and 2 Sept. 2014. The cabbage health ratings were: 1= dead or kinked stem, 2= transplant leaves had yellowed or senesced, 3= transplant had not grown since transplanting, 4= transplant had developed three to six more leaves, 5= transplant had developed 7 or more leaves.

Chlorophyll content

Chlorophyll content was measured with a SPAD-502Plus meter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ), on 12 Sept. 2013 and 9 Sept. 2014. The SPAD meter readings were taken on the first leaves from the growing point that measured two cm or larger. The three values were averaged for each plant. Plants for scanning were selected at even intervals in each subplot in each rep for a total of 6 plants.

Pest management

Pests were present both years, and management events are presented in Table 2.1. Cabbage loopers (*Trichoplusia ni* Hubner) were the only pest sprayed in both years with the exception of 23 Sept. 2014 in which aphids (*Aphis gossypii* Glover) were also present.

Harvesting and grading

Harvest took place on 7 Nov. and 31 Oct. in 2013 and 2014 respectively. In each plot 24 plants were harvested and graded. Heads were removed from the lower leaf base and separated into marketable and non-marketable categories. Marketable heads were defined as a head that was equal to or larger than 27 cm circumference. Head counts were taken from both categories. Mean width of marketable heads was determined in 2014 only.

Soil microbial biomass

Soil samples for microbial biomass estimation were collected from a depth of 15 cm from the cover crop treatments in the late planted cabbage only on the 5 Nov. in both years. Samples were transported to the laboratory and extracted following the Chloroform Fumigation Extraction Method (Vance, 1987) with minor modifications. Extracts were analyzed using a Phoenix 8000, UV-Persulfate TOC Analyzer (Teledyne Tekmar, Mason, OH) in 2013 or a Torch Combustion TOC/TN Analyzer (Teledyne Tekmar, Mason, OH) in 2014.

Data analysis

Data sets were analyzed with SAS statistical software version 9.3 (SAS Inc. Cary, NC). The PROC GLIMMIX method was used, and mean separation was done by the Least Significant Difference ($P \leq 0.05$) method. Because cover crop-by-year interactions were significant, data were analyzed and presented separately by year. Also, interactions existed between cover crops and planting date in some data sets.

Results

Weather

In 2013 (Figure 2.1) temperatures trended equal to or higher than the 30 year average both during the cover crop growth period and cabbage growth period (Iowa Environmental Mesonet, 2015). Rainfall was below the 30 year average for the entire season. In 2014 temperatures trended equal to or lower than the 30 year average both during the cover crop growth period and cabbage growth period. Rainfall was above the 30 year average for the entire season with the exception of July and November.

Cover crop biomass

Sorghum-sudangrass produced the greatest amount of aboveground biomass compared to the control, cowpea, and oat cover crops in 2013 (Fig. 2.2). Cowpea produced the least amount of aboveground biomass when compared to buckwheat and sorghum-sudangrass. Cowpea was not different from black oats or control treatments. In 2014 cowpea and buckwheat produced less biomass compared to sorghum-sudangrass and control but were not different from black oats. Sorghum-sudangrass and control had more biomass compared to buckwheat and cowpea but were not different from black oats.

Nitrate measurement

In 2013, concentration of nitrates measured was highest in cowpea at week one (Fig. 2.3). In week three buckwheat nitrate concentration rose to a level the same as cowpea. At this time buckwheat and cowpea both had higher nitrate concentration than the control, black oats, or sorghum-sudangrass. During week four buckwheat maintained the highest concentration of nitrate compared to black oats and cowpea. From week five to week eight there were no differences present between treatments. In 2014 the first three weeks of data collection showed no difference in nitrate concentration. At week four, cowpea and black oats had higher nitrate concentrations than the control. At week five, cowpea and black oats had higher nitrate levels than control and buckwheat. At week six, the cover crops maintained the same differences as week five. In weeks seven and eight there were no differences in soil nitrate concentration among any of the cover crop treatments.

Plant health score

In 2013 the health score assigned on 22 Aug. (day one) (Table 2.2) the cabbage planted in the cowpea-early treatment had the highest health score. Cowpea-late treatment had the second highest health score. All other treatments had significantly lower health score than those two treatments. Cover crop effects were significant but planting time was not. On 29 Aug. (day two) in 2013 the cowpea-early and cowpea-late treatment were no longer different from each other but both treatments were still higher than other treatments. In 2014 on 15 Aug. (day one) cabbage planted in cowpea-late treatment had higher health score than buckwheat-late, black oats-late, sorghum-sudangrass-late, or sorghum-sudangrass-early. Sorghum-sudangrass-late had lower health score than control-early, buckwheat-early, cowpea-early or cowpea-late. On 2 Sep. (day two) in 2014 the cover crops and planting date were not significant.

Chlorophyll content

In 2013 SPAD readings of cabbage leaves (Table 2.2) were higher in the cowpea-early treatment when compared to all other treatments except black oats-early. The sorghum-sudangrass-late treatment was lower when compared to control-early, buckwheat-early, black oats-early, cowpea-early, or cowpea-late treatments. In 2014 cover crops effects were not significant but planting date and interactions did exist.

Cowpea-early treatment was higher than control-late, buckwheat-early, buckwheat-late, cowpea-late, and sorghum-sudangrass-early.

Cabbage yield and head count

In 2013 marketable weight was highest in the cowpea-early treatment followed by cowpea-late (Table 2.3). All other cover crops had similar marketable weight. The results for marketable head number followed the same pattern as marketable weight. In 2014 the marketable cabbage weight was higher in the cowpea-early and cowpea-late treatment when compared to all other treatments except buckwheat-early or buckwheat-late. Yield was lower in the control-late treatment than cowpea-early cowpea-late, buckwheat-early, or buckwheat-late treatments. With respect to number of marketable heads cowpea-late had higher head count when compared to all other treatments except cowpea-early, buckwheat-early or buckwheat-late treatments. For non-marketable cabbage weight in 2013, cowpea-early had the lowest non-marketable weight compared to all other treatments. In the 2014 the non-marketable cabbage weight was lowest in the cowpea-late treatment when compared to black oats-early, black oats-late, control-early, control-late or sorghum-sudangrass-early treatments.

Average head width

Average cabbage head width was measured only in 2014 (Table 2.3). There were no significant differences among cover crop or planting date treatments.

Discussion and Conclusion

The cover crop that had the best influence on the cabbage crop when compared to the control treatment was cowpea. Though not always statistically significant cowpea trended to benefit the cabbage compared to the control treatment in health score, SPAD, marketable weight and head count. This could be attributed to the additional nitrogen cowpea can add to the soil through nitrogen fixation. Benefits shown by the cabbage demonstrates cowpea's ability to fix nitrogen (Appiah et al., 2015; Martins et al., 2015). Nitrogen fixation combined with a low carbon to nitrogen ratio in the aboveground biomass of the cowpea (Creamer and Baldwin, 2000) contributed to availability and quick access of available nitrogen to plants (Kuo et al. 1997). Higher SPAD readings in cabbage plants grown in the cowpea treatment validate the data. Higher nitrate nitrogen collected in the leachate from the cowpea treatment supports the high nitrogen concentration in that treatment. This is similar to findings by Kuo et al. (1997) who found that short term mineralized nitrogen levels were increased by a legume that had a low carbon to nitrogen ratio. This is also supported by cowpea having some of the highest combined soil ammonia and nitrate levels across both years 8 d after transplanting (data not shown). For growers interested in improving cabbage performance with a preceding cover crop, our results suggest planting of cowpea which is a warm season legume. This finding agrees with Wang et al., (2008) who found that cowpea as a summer cover crop increased the yield of the following lettuce (*lactuca sativa* L.) and muskmelon crop (*cucumis melo* L.) compared to the control. Within the cowpea treatment comparing cabbage performance between the two transplanting dates, there is no clear pattern to show which date had the greater benefit to yield. When differences did exist the cowpea-early treatment always had the advantage. An additional benefit among the cover crops is the cowpea treatment seen in this study had the lowest non-marketable weight relative to the control in 2013. This means that a warm season legume cover crop may reduce the non-marketable portion of the crop which would reduce financial losses and increase profitability.

With the high amount of above ground biomass experienced in the plot combined with the high carbon to nitrogen ratio of sorghum-sudangrass(Creamer and Baldwin, 2000), we had anticipated that sorghum-sudangrass would decrease cabbage yield. This was primarily because of nitrogen immobilization we were expecting to be caused by the sorghum-sudangrass residue (Kuo et al., 1997). Detrimental effects to a following cabbage crop in a similar study to ours was seen from sorghum-sudangrass on cabbage head weight by Finney et al., (2009) further confirming our prediction. Contrary to our prediction the data we have collected does not show detrimental effects from sorghum-sudangrass compared to the control.

The effects of black oats and buckwheat on cabbage health score, SPAD and yield are not clear. This finding disagrees with Kumar et al., (2009) who saw negative effects of common oats (a close relative to black oats) and buckwheat on lettuce and swiss chard [*Beta vulgaris* var. *cicla* (L.) K. Koch] yield. This does not mean that black oats or buckwheat is not a valuable cover crop in vegetable rotations. Even though not measured in this study there are benefits these cover crop may offer while growing in the field prior to soil incorporation. Common oats can offer weed suppression (Bjorkman and Shail, 2010; Curell, 2012) and prevention of soil erosion (De Baets et al., 2011; Horton et al., 1994). Buckwheat can also offer weed suppression (Björkman and Shail, 2013;

Tominaga and Uezu, 1995) with the added benefit of serving as a pollinator habitat (Clark, 2007; Treadwell and Huang, 2008) and predatory insect habitat (Simpson et al., 2011).

Our study does not show a benefit planting 8 d after cover crop soil incorporation over planting immediately after cover crops soil incorporation. Within cover crop treatments, except cowpea in 2013, there were no differences in marketable weight or number of cabbages. In 2013 the cowpea-early treatment did have a higher yield than the cowpea-late treatment.

Our findings do not agree with (Ngouajio, 2011; Ackroyd and Ngoujio, 2011) who suggests that waiting a longer period after cover crop soil incorporation of a cover crop is beneficial to the following vegetable crop. The study by Ackroyd and Ngoujio, (2011) studied three cover crops from the brassica family and their effect on a direct seeded muskmelon crop as compared to our study. For farmers looking to increase marketable yield, the data collected shows no benefit to waiting 8 days to plant the following cash crop.

There were no detectable differences in the soil microbial biomass carbon content of the treatments in either year (data not shown). Contrary to our results Moore et al., (2000) has seen differences in microbial biomass carbon with diverse crop rotations that were in practice for many years. Moore et al., (2000) suggests that the amount of soil microbial biomass carbon differed based on the amount and diversity of plant residues. Since we measured soil microbial biomass carbon after six months of treatment implementation this may explain why we have not seen any differences measured even though the treatments implemented in our study diversified the field’s cropping sequence.

Cover crops planted during a short warm summer season can have a positive effect on the yield of a following fall cabbage crop. Farmers looking to increase yield can plant warm season legumes such as cowpea to provide nitrogen fixation and reduce nitrogen immobilization upon being tilled into the soil for the following vegetable crop. Warm-season legumes can not only boost yield but also decrease the non-marketable portion of the crop thereby reducing lost financial inputs to unsaleable product. From the data in this study there is no consistent evidence suggesting that a later planting date after cover crop incorporation has any positive effect on yield

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Table 2.1. Pest management products and dates of application in 2013 and 2014.

Date	Chemical applied	Rate/ha
	2013	
23 Aug.	Esfenvalerate[z] 8.4%	0.045 kg
6 Sep.	*Bacillus thuringiensis*[y] 23.7%	1.12 kg
13 Sep.	*Bacillus thuringiensis* 23.7%, Pyrethrins[x] 5%	1.12 kg, 1.462 l
27 Sep.	*Bacillus thuringiensis* 23.7%	1.12 kg
10 Oct.	*Bacillus thuringiensis* 23.7%	1.12 kg
	2014	
23 Sep.	Acetamiprid[w] 70%, Novaluron[v] 9.3%	292 ml, 876ml
29 Sep.	23.7% *Bacillus thuringiensis*,	1.68 kg

[z]Dupont Asana XL (E. I. du Pont de Nemours and Company, Wilmington, DE)

[y]Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351 fermentation solids spores and insecticidal toxins [Dipel DF (Valent Biosciences Corp., Libertyville, lL)]

[x]PyGanic Crop Protection EC 5.0II (MGK, Minneapolis, MN)

[w]Assail (UPI, King of Prussia, PA)

[v]Rimon .83 EC (Chemtura Corporation, Middlebury, CT)

Table 2.2 Health score and SPAD readings as influenced by cover crop and planting date.

	Day 1[z]		Day 2		SPAD[y]	
Cover crop/planting date	2013	2014	2013	2014	2013	2014
Control						
Early	3.0 c[x]	3.9 ab	3.5 b	4.2	54 bc	57 ab
Late	3.0 c	3.5 abcd	3.2 b	4.4	52 bcd	53 c
Buckwheat						
Early	3.0 c	3.7 abc	3.3 b	3.9	54 bc	53 bc
Late	3.0 c	3.4 bcd	3.0 b	3.8	51 cd	54 bc
Cowpea						
Early	3.8 a	3.9 ab	4.4 a	4.5	59 a	58 a
Late	3.3 b	4.0 a	4.4 a	4.3	54 bc	53 bc
Black oats						
Early	3.0 c	3.6 abcd	3.3 b	3.8	55 ab	56 abc
Late	3.0 c	3.6 cd	3.1 b	4.0	51 cd	56 abc
Sorghum-sudangrass						
Early	3.0 c	3.3 cd	3.1 b	3.9	53 bcd	54 bc
Late	2.9 c	3.1 d	3.0 b	3.9	49 d	55 abc
Significance						
Cover crop	**[w]	*	***	NS	*	NS
Planting date	NS	*	**	NS	***	*
Cover crop × planting date	**	NS	NS	NS	NS	**

[z]Day 1 represents health scores assigned on 22 and 15 Aug. in 2013 and 2014, respectively. Day 2 represents health scores assigned on 29 Aug. and 2 Sep. in 2013 and 2014, respectively. Health score rating based on the following five point scale: 1= dead, 2= leaf yellowing or lower leaves were drying up, 3= no growth since transplanting, 4= transplant has three to six new leaves, 5= transplant has seven or more new leaves.

[y]Chlorophyll estimation as assigned by the SPAD meter. The higher the rating the more chlorophyll that is present in the leaf.

[x]Mean separation within columns was done by least significant difference test ($P \leq .05$). Values within each column sharing the same letter are not different.

[w]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 2.3. Cabbage yield and head count as affected by cover crop and planting time in 2013 and 2014.

	Marketable[z]				Non-marketable[y]		Head width[x]
	2013		2014		2013	2014	2014
Cover crop/planting date	weight ($kg \cdot ha^{-1}$)	Number (per ha)	weight ($kg \cdot ha^{-1}$)	Number (per ha)	weight ($kg \cdot ha^{-1}$)	weight ($kg \cdot ha^{-1}$)	(cm)
Control							
Early	600 c[w]	2,500 c	3,300 bc	6,900 dc	3,300 a	5,100 ab	9.2
Late	500 c	1,700 c	1,200 c	3,100 d	3,400 a	5,800 a	9.0
Buckwheat							
Early	900 c	3,100 c	6,200 ab	11,000 abcd	3,500 a	3,900 bcd	9.7
Late	0 c	0 c	6,000 ab	13,500 abc	3,000 ab	3,400 cd	9.2
Cowpea							
Early	10,700 a	25,500 a	7,900 a	15,500 ab	900 c	4,000 bcd	9.9
Late	7,400 b	19,700 b	8,400 a	18,600 a	2,100 b	2,900 d	9.4
Black oats							
Early	300 c	1,000 c	2,700 bc	6,600 dc	2,800 ab	5,200 ab	9.2
Late	600 c	2,000 c	2,200 bc	4,800 d	2,600 ab	4,800 abc	9.5
Sorghum-sudangrass							
Early	200 c	700 c	2,000 bc	5,200 dc	2,500 ab	4,700 abc	9.3
Late	0 c	0 c	2,500 bc	7,500 bcd	2,500 ab	4,000 bcd	8.6
Significance							
Cover crop	***[v]	***	*	*	**	*	NS
Planting date	**	**	NS	NS	NS	NS	NS
Cover crop × planting date	**	**	NS	NS	NS	NS	NS

[z]Marketable cabbage has a head circumference ≥27 cm.

[y]Non-Marketable cabbage has a head circumference <27 cm.

[x]Average head width of 6 marketable cabbage heads in 2014 only.

[w]Mean separation within columns was done by least significant difference test (P≤.05). Values within each column sharing the same letter are not different.

[v]NS, *, **, *** Nonsignificant or significant at P ≤ 0.05, 0.01, or 0.001, respectively, based on least significant difference test

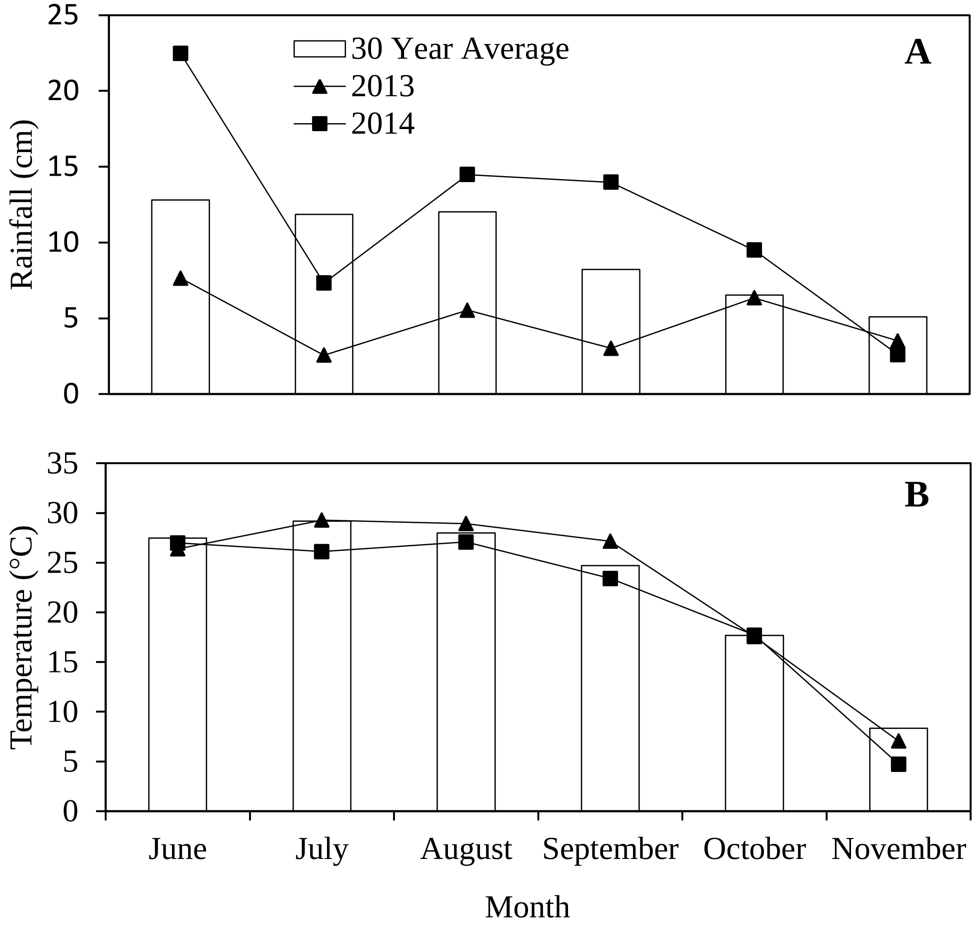

Figure 2.1 Accumulated monthly rainfall (A) and average monthly daytime high temperature (B) in 2013 and 2014 compared with the thirty year average. Data was retrieved from the Iowa Environmental Mesonet, 2015.

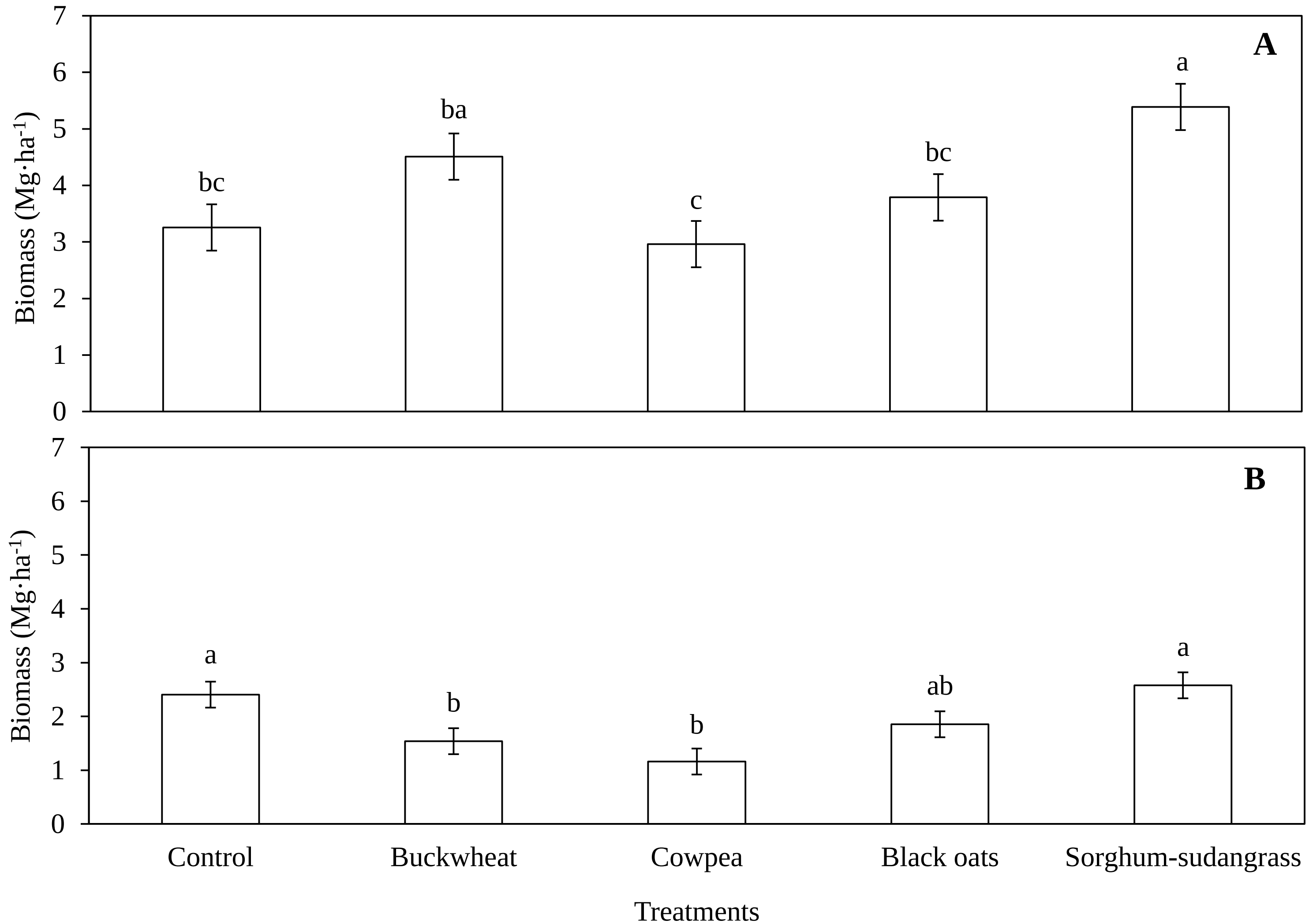

Fig. 2.2 Cover crop above ground biomass in year 2013 (A) and 2014 (B). Mean separation between treatments was done by least significant difference test (P≤.05). Treatments not sharing the same letters are different. Error bars are represented underneath each letter for specific treatments.

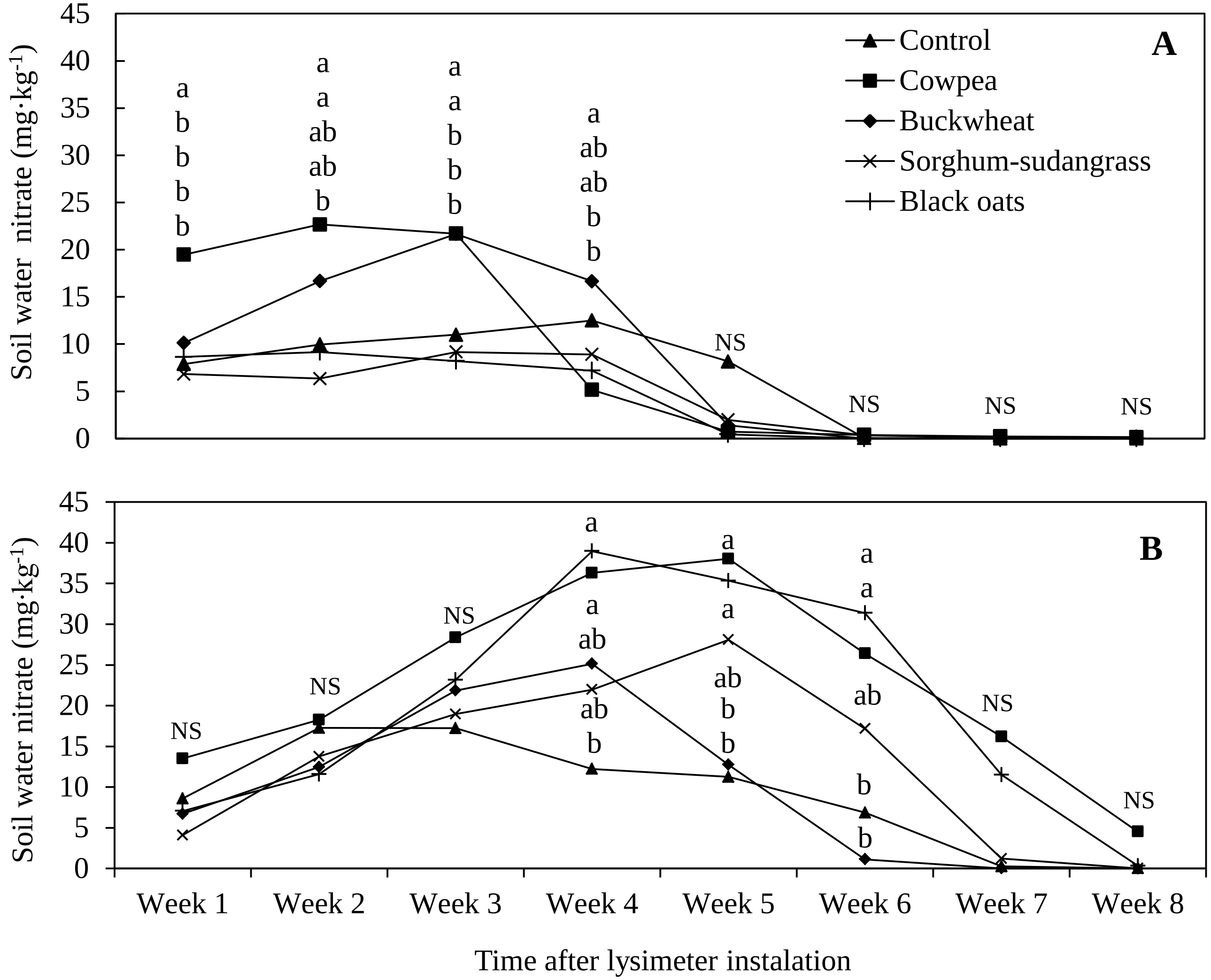

Figure 2.3 Nitrate nitrogen (mg·kg^{-1}) captured via lysimeters as influenced by cover crop over time in year 2013 (A) and 2014 (B). Weeks on x axis represent the time passed since lysimeters were installed with week one occurring on 20 Aug. and 29 Aug. in 2013 and 2014, respectively. Mean separation at each date was done by least significant difference test (P≤.05), ns = nonsignificant. Data points not sharing the same letter are different.

CHAPTER 3. SUMMER COVER CROPS AND PLANTING DATE INFLUENCE WEED POPULATION, SOIL NITROGEN CONCENTRATION, AND LETTUCE YIELD AND QUALITY

Modified from a paper written for HortTechnology

Raymond Kruse[1] and Ajay Nair[1*]

Abstract

Cover crops can be used as a sustainable weed management tool in crop production systems. Cover crops have the ability to suppress weeds, reduce soil erosion, increase soil organic matter, and improve soil physical, chemical, and biological properties. In the North Central region, including Iowa, much cover crop research has been conducted in row crop systems, mainly corn (*Zea mays*) and soybean (*Glycine max*) where cover crops are planted at the end of the growing season in September or October. There is little information available on the use of cover crops in vegetable production systems and, more over information is limited on the use of summer cover crops for fall vegetable production. This study investigated how short duration summer cover crops impact weed suppression, soil properties, and yield and quality aspects in lettuce

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[1]Department of Horticulture, Iowa State University, Ames IA 50010

*To whom correspondence should be addressed E-mail nairajay@iastate.edu

production. The study also examined appropriate planting dates of lettuce transplants after soil incorporation of cover crops. Experimental design was a randomized complete block split-plot design with four replications. Whole plot consisted of cover crop treatments: buckwheat (*Fagopyrum esculentum* 'Mancan'), cowpea (*Vigna unguiculata* 'Iron & Clay'), black oats (*Avena strigosa* 'Black Oats'), sorghum-sudangrass (*Sorghum bicolor ssp. drummondii* 'Grazex II'), or control (no cover crop) where weeds were left to grow unchecked. The subplot treatment consisted of two lettuce transplanting dates: planted immediately or or eight days after cover crop soil incorporation. Cash crop was a fall planted butter head lettuce (*Lactuca sativa* 'Adriana'). Data were collected on weed biomass, soil nutrient concentration, and lettuce growth and yield attributes. Cover crops significantly reduced weed biomass as compared to the control treatment. Cowpea, a legume, increased soil nitrogen concentration and contributed to higher lettuce yield and improved quality. Cowpea also enhanced lettuce growth and led to an early harvest. Sorghum-sudangrass showed trending evidence of detrimental effects to the marketable lettuce crop. With respect to planting date of lettuce no conclusion can be drawn as to which date is better. This study demonstrates that cover crops can successfully be integrated into vegetable cropping systems; however, cover crop selection is critical.

Introduction

Depending on their production systems and markets, vegetable growers can grow crops that either occupy an entire growing season or a few months of the growing season. In a late planted fall vegetable production system where no other cash crop occupies the soil for the preceding part of the season. If left unchecked the preceding growing time period is an opportunity for weeds to grow and contribute large amounts of seeds (Kumar et al., 2009). During this summer fallow season many Midwest vegetable growers manage weeds by means of tillage or herbicides. Although effective, herbicides and excessive tillage lead to environmental issues such as herbicide resistance (Chatham et al., 2015) and reduced soil organic matter (Reicosky et al., 1995). Cover crops are one possible alternative to tillage and herbicides for weed control that offer additional benefits to the soil and environment while also offering the possibility of increasing or maintaining vegetable yield (Kumar et al., 2009). Studies have reported successful weed suppression using cover crops (Bugg and Dutcher, 1989; Kumar et al., 2009) while also influencing yield of the successive vegetable crop (Sainju et al., 2002). Observed mechanisms of weed suppression reported are weed seed reduction (Kumar et al., 2009), allelopathy (Rueda-Ayala et al., 2015) and reduction of weed seed germination following cover crop soil incorporation (Kumar et al., 2009).

Not only can cover crops be a suitable alternative to herbicides and tillage but they can provide other environmental services. Soil organic matter is one aspect that cover crops can influence in a positive way (Mukherjee and Lal, 2015). Ding et al. (2006) reported an increase in soil organic matter using cover crops compared to a no cover crop control. Cover crops have also been shown to benefit pollinator resources (Clark, 2007), improve soil fertility (Teasdale, 1996), and improve soil microbial biomass (Buyer et al., 2010). Corak et al. (1991) and De Baets et al. (2011) reported reduction in soil erosion especially with fibrous rooted cover crops such as common oats (*Avena sativa*).

The variable climate and narrow seasonal window for growing vegetables in Iowa demands innovative integration of cover crops and cover crop mixtures. Vegetable growers now foresee the importance and relevance of cover crops in their cropping systems. Thus, integration of cover crops in to vegetable cropping systems bears paradigm importance. There is even less research on how summer cover crops influence vegetable crops in the fall. Few studies have experimented with summer cover crops (Creamer and Baldwin, 2000) and their influence on vegetables (Wang et al., 2008a) but more information is needed on the type of cover crop, biomass they can generate, and effects they can have on soil and succeeding crops. Additionally, appropriate planting time of vegetables, after cover crop soil incorporation, needs to be evaluated, given potential negative impact cover crops can have on succeeding vegetables (Acroyd and Ngouajio, 2011).

The primary objective of this study was to investigate effects of summer cover crops on fall lettuce production in conjunction with evaluating two planting dates of lettuce. This information can help growers identify a cover crop suitable for the summer fallow season that can provide weed suppression, improve soil properties, and increase quality and yield of the fall lettuce crop.

Materials and Methods

Experiment site

This experiment was conducted at the Iowa State University Horticulture Research Station, Gilbert, IA during the 2013 and 2014 growing seasons. The experiment was carried out on the same plot area for both years. The original soil type was Clarion which is a fine-loamy, Typic Hapludoll with a slope of 2% to 6%. The sand, silt, and clay fractions of the modified layer are 68%, 20% and 12%, respectively using the pipet method of particle size analysis. The cation exchange capacity was 9.46 meq/100g.

Predominant weeds in soil include: common lambsquarter (*Chenopodium album)*, green foxtail (*Setaria viridis*), greenflower pepper weed (*Lepidium densiflorum*), Pennsylvania smartweed (*Polygonum pensylvanicum*), prickly lettuce (*Lactuca serriola*), shepherdspurse (*Capsella bursa-pastoris*), and yellow foxtail (*Setaria pumila*).

Experimental design

This experiment had a split-plot randomized complete block design with four replications. Individual plots were 612 ft^2 (25.5-ft long by 24-ft wide). Whole plot treatments were buckwheat (*Fagopyrum esculentum* 'Mancan'), cowpea (*Vigna unguiculata* 'Iron & Clay'), black oats (*Avena strigose* 'Black Oats'), sorghum-sudangrass (*Sorghum bicolor* ssp. *Drummondii* 'Grazex II') or control (no cover crop). The subplot treatment was planting date of lettuce after cover crop soil incorporation (immediately or 8 d after). Throughout this paper when discussing a specific combination of cover crop and planting date the following short form will be used ex. "cowpea-early" where "cowpea" denotes the cover crop and "early" denotes the immediate planting date of lettuce. Likewise, "cowpea-late" denotes "cowpea" cover crop and "late" denotes lettuce planting eight d after cover crop soil incorporation.

Cover crop establishment and growth

Cover crop seeding took place on 2 June 2013 and 12 June 2014. Sorghum-sudangrass seeding was delayed by 4 d in 2014 due to delayed shipping of seed. Before cover crop seeding the plot was roto-tilled using a John Deere 550 roto-tiller (John Deere, Moline, Il) to a depth of 4 to 6 in. A 42 in. variable rate Gandy drop spreader (Anertec & Gandy Company, Owatonna, MN) was used to seed the cover crop at predetermined calibrated settings. The seeding rates of the cover crops consisted of: 50, 85, 60, and 50 lb·ac^{-1} of buckwheat, cowpea, black oats, and sorghum-sudangrass, respectively. An additional shallow pass with the roto-tiller was made to incorporate the cover crops seeds to a depth of 2 in. Above ground cover crop biomass was collected on 4 Aug. in 2014 prior to cover crop soil incorporation. Cover crop biomass was collected using two 0.25 m^2 quadrats from each cover crop plot. Weed biomass was also pulled from the same quadrat. Weeds were separated into broadleaf weed and grass weeds. Cover crop and weed biomass were dried in an oven for 3 days at 67°C and then weighed. Cover crops in the field were terminated using a Rhino ORC 10 flail mower (Rhino, Gibson City, Il) on 6 Aug. 2013 and 5 Aug. 2014 followed by roto-tilling to a depth of 8 to 10 in.

Transplant production and field planting

To account for two planting dates in the field, two batches of lettuce seeds were seeded, eight days apart. Pelleted lettuce seeds were seeded in 98 cell-trays using LC1 soilless growing medium (Sun Gro Horticulture Canada Ltd, Seba Beach, AB, Canada) on 8 July and 15 July in 2013 and 8 July and 16 July in 2014. Once emerged, seedlings were fertigated with 150, 42, and 145 ppm of nitrogen, phosphorous, and potassium respectively on a weekly basis. The fertilizer solution was a mixture of water soluble powders consisting of 21N-2.2P-16.6K and 15N-2.2P-12.45K-4Ca-2Mg (J.R. Peters, Inc., Allentown, Pa). During both years the greenhouse was set to 69°F. Seedlings were grown in the greenhouse and hardened off for a week before transplanting in the field.

After cover crop soil incorporation raised beds with drip irrigation were created using a Nolt's RB448 raised bed mulch layer (Nolt's Produce Supplies, Leola, PA). Each cover crop treatment had four beds. Beds were spaced 6 ft. apart (center-to-center) with the bed surface being 2 ft. wide on top. Flow rate of installed drip tape was 0.22 gal/100 ft/min. Lettuce was transplanted using a Rain-Flo 1600 Series II water wheel transplanter (Rain-Flo Irrigation, East Earl, PA). Each bed had two rows of lettuce that were 9 in. apart and were staggered. Plants were 12 in. apart within rows. The subplot treatment with early planting of lettuce was transplanted the same day as cover crop soil incorporation. This occurred on 6 Aug. 2013 and 5 Aug. 2014. Late planting took place 8 d after the early planting in both years. Lettuce crop in both years was provided a total N, P, and K dose of 72, 17, and 68 $lb \cdot ac^{-1}$, respectively, using the fertilizer 21N-2.2P-16.6K (J.R. Peters, Inc., Allentown, Pa). The soluble fertilizer was injected into the irrigation system using a DosmaticPlus inline volumetric flow injector (Hydro Systems Company, Cincinatti, OH).

Leaf chlorophyll content

Leaf chlorophyll content was estimated on 12 Sept. 2013 and 9 Sept. 2014 using a SPAD-502 Plus meter (Konica Minolta Inc., Ramsey, NJ). Within each cover crop and planting time treatment, three readings were collected from each plant and averaged, six plants were averaged from each treatment. Readings were collected on three youngest leaves that were a minimum of 2 cm wide. Measurements from each subplot were averaged and the averaged number was used for statistical analysis.

Soil samples

Soil samples were collected at five different times throughout the lettuce growing season. The times are as follows: 1= cover crop planting, 2= early planting, 3= late planting, 4= first lettuce harvest, and 5= late fall. These times corresponded with the following dates in 2013 respectively; 2 June, 4 Aug., 14 Aug., 10 Sept., and 5 Nov. In 2014 soil sampling times corresponded with the following dates respectively; 12 June, 4

Aug., 13 Aug., 10 Sept., and 5 Nov. Prior to analysis soils were sieved through a 10 mm sieve. Nitrate and ammonium were extracted using a 2 N KCl solution. Extracts were analyzed on a Lachat QuikChem 8000 Fia+ (Hach Company, Loveland, CO). For other cation analysis a Mehlich III solution was used. Extracts were then were read on either a Spectro Ciros ICP-OES (SPECTRO Analytical Instruments Inc, Kleve, Germany) or a Thermo Scientific ICAP6300 Radial (Thermo Fisher Scientific, Cambridge, United Kingdom).

Plant health rating

Health ratings were conducted on 20 Aug. 2013 and 15 Aug. 2014. Health ratings/score were assigned based on a five point system. The categories are as follows: 1= transplant is dead, 2= transplant has leaf yellowing or lower leaves are drying up, 3= transplant has not grown since transplanting, 4= transplant has grown up to six more leaves after transplanting, and 5= transplant has grown seven or more leaves after transplanting. A total of 24 plants were sampled within each subplot treatment.

Plant size

On 18 Sept. 2013 and 10 Sept. 2014 prior to the first harvest of lettuce, plant size was measured. A tool was developed using different sized rings bound on a similar plane attached to three wooden legs that were 18 cm above the lettuce plant. The tool was placed over the lettuce plants that was put into one of the five categories based on what size ring they were equal to or larger than on the tool. Plant size categories are as follows: 1= less than 10 cm, 2= greater than or equal to 10 cm, 3= greater than or equal to 15 cm, 4= greater than or equal to 20 cm, or 5= greater than or equal to 25 cm. The middle 24 plants of each subplot were measured.

Pest management

Cabbage loopers (*Trichoplusia ni*) and aphids (*Aphis gossypii*) were primary pests in both years. Table 3.1 lists products and dates of application of those products. In 2013 cabbage loopers were the only pest sprayed for. Cabbage loopers and aphids were sprayed for on 23 September 2014. On 29 September 2014 only cabbage loppers were sprayed for.

Harvest

Cover crop and planting date affected the time taken to grow the lettuce from transplant stage to marketable stage. For this reason treatments were assessed for harvest on a weekly basis to achieve the optimal size so that marketable and nonmarketable portions of lettuce were best represented for data analysis. The decision to harvest was determined when 50% or more of plants at the subplot level were at optimal marketable size. Harvesting for specific cover crop and planting date combinations took place on following dates in 2013: cowpea-early on 20 Sep., cowpea-late on 27 Sep., and all others on 2 Oct. In 2014, harvesting for specific cover crop and planting time combinations took place on following dates: 11 Sep. for cowpea-early, buckwheat-early, control-early and cowpea-late, and all other remaining treatment combinations were harvested on 24 Sep. Standards for marketable lettuce included a head size of approximately 20 cm wide or larger with little to no insect, disease or environmental damage. If the head was less than 20 cm in diameter and/or had excessive damage, the head was considered non marketable. Once lettuce number and weight for marketable and non-marketable categories were collected, two representative heads were chosen from the marketable category to quantify leaf number, leaf area, and head dry weight. Leaf number was quantified by pulling all leaves off the center stalk measuring 2 cm in size or larger. Only leaves that pulled clean from the head of lettuce were measured for leaf area. Leaf area was determined using a Li-cor LI-3100 scanner (Li-cor Inc., Lincoln, NE). After leaf area estimation, leaves were dried in an oven for three days at 67°C for dry weight estimation.

Data analysis

Data collected was analyzed using the SAS statistical software 9.3 version (SAS Inc. Cary, NC). PROC GLIMMIX was used and mean separation was done using least significant difference ($P \leq 0.05$). In the absence of any interaction, data from both years were pooled. Differences between cover crops and cover crop × planting date interactions were analyzed using the lines statement in PROC GLIMMIX.

Results

Weather

Rainfall in 2013 was much below the 30 year average for the entire growing season as seen in Fig. 3.1 (Iowa Environmental Mesonet, 2015). Rainfall in 2014 was above the 30 year average for the entire growing season except for July and August. Temperatures were higher in 2013 than in 2014 for the span of the experiment.

Cover crop biomass

Above ground cover crop biomass was measured and ranged from 3.0 $Mg \cdot ha^{-1}$ in the cowpea treatment to 5.4 $Mg \cdot ha^{-1}$ in the sorghum-sudangrass treatment in 2013 (data not reported). In 2014 cover crop biomass ranged from 1.2 $Mg \cdot ha^{-1}$ in the cowpea treatment and 2.6 $Mg \cdot ha^{-1}$ in the sorghum-sudangrass treatment in 2014. Oats and buckwheat produced biomass values in between that of cowpea and sorghum-sudangrass.

Weed biomass

In 2013 weed biomass was highest in the control treatment for both broadleaves and grasses (Table 3.2). Buckwheat had the lowest weed biomass for both broadleaves and grasses as compared to all other cover crops with the exception of broadleaves in black oats. Cowpea, black oats, and sorghum-sudangrass were not different from each other in weed suppression. In 2014, weed biomass was highest in the control and cowpea treatments. There was only one exception in the cowpea treatment in the broadleaf category where weed biomass was not different from the buckwheat, black oats or sorghum-sudangrass. Buckwheat numerically had the lowest biomass of all the cover crops but was not significant.

Leaf chlorophyll content

There was no interaction between cover crop and planting dates in both years (Table 3.3) so main and subplot effects were presented separately. In 2013 SPAD was lowest in the sorghum-sudangrass treatment. All other cover crops were higher than sorghum-sudangrass but were not significantly different from each other. Early and late lettuce planting dates were different from each other with early planted lettuce having a higher SPAD reading. In 2014 lettuce in the black oats and sorghum-sudangrass cover crop plots had higher SPAD readings than the cowpea and control treatments. Planting date was significant in 2014 with late planted lettuce having a higher SPAD reading than early planted lettuce.

Soil nitrogen

Soil nitrogen was measured at specific time periods that included, cover crop seeding, early lettuce planting date, late lettuce planting date, first lettuce harvest, and late fall (40 d after first lettuce harvest). In 2013, soil nitrogen concentrations were not different at cover crop seeding or early lettuce planting date (Fig. 3.2). At the late lettuce planting date soil nitrogen concentration was highest in the cowpea treatment with all other treatments having no significant differences between each other. At the first lettuce harvest, cowpea treatment maintained the highest concentration of soil nitrogen. Black oats and control treatment were, at this time, higher in soil nitrogen than sorghum-sudangrass. At the late fall time period, the same trends remained with the addition of buckwheat having higher soil nitrogen than sorghum-sudangrass. In 2014, soil nitrogen concentrations were not different at cover crop seeding and the early lettuce planting date. At the late planting date, cowpea had more soil nitrogen than buckwheat. At the first lettuce harvest period sorghum-sudangrass had more soil nitrogen than the control. In the late fall, cowpea had more nitrogen than the control or buckwheat.

Soil phosphorous and potassium

Soil samples taken for phosphorous and potassium were taken the same time as the ones taken for soil nitrogen analysis. Interactions were observed between years so data was analyzed separately by year. No differences were observed in soil concentrations of phosphorous or potassium between any cover crop at any of the sampling dates, thus data is not shown.

Health rating/score

Interactions were present in both years between cover crop and planting date (Table 3.4). In 2013, the health score was the highest for cowpea-early followed by cowpea-late treatment. All other treatments were lower than cowpea-late but not significantly different from each other.   In 2014 control-early, buckwheat-early, and cowpea-early had higher health scores than sorghum-sudangrass-early, control-late, buckwheat-late, black oats-late or sorghum-sudangrass-late treatments.

Head diameter

In 2013 cowpea-early had the largest head diameter with the exception of cowpea-late (Table 3.5). In 2014 cowpea-early and control-early had the larger head diameter when compared to buckwheat-late, control-late, black oats-early, black oats late, sorshum-sudangrass-early, and sorghum-sudangrass-late. Sorghum-sudangrass-early and sorghum-sudangrass-late trended to have the lowest head diameters in both years.

Marketable yield

In 2013, marketable lettuce yield was higher in the cowpea-late when compared to cowpea-early, black oats-late, sorghum-sudangrass-early, or sorghum-sudangrass-late (Table 3.6). Marketable number of heads per acre were higher in the buckwheat-late when compared to the black oats-late, sorghum-sudangrass-early, and sorghum-sudangrass-late. In 2014 the marketable lettuce yield was higher in the control-early, control-late, cowpea-early, and black oats-early when compared to buckwheat-early, cowpea-late, black oats-late, sorghum-sudangrass-early and sorghum-sudangrass-late. Marketable heads were highest in cowpea-early compared to all other treatments with the exception of control-early, control-late, and black oats-early treatment.

Non-marketable yield

Non-marketable lettuce yield was higher in the cowpea-late and black oats-late when compared to the buckwheat-late and cowpea-early treatment in 2013 (Table 3.6). In 2014, non-marketable lettuce yield was highest in the sorghum-sudangrass-early with the exception of black oats-late and sorghum-sudangrass-late treatments.

Leaf area and number per head

In 2013, cowpea-late had the higher leaf area per head when compared to buckwheat-late, black oats-late, cowpea-early, sorghum-sudangrass-early, or sorghum-sudangrass-late (Table 3.5). In 2014 cowpea-early had the higher leaf area when compared to buckwheat-early, buckwheat-late, cowpea-late, black oats-late, sorghum-sudangrass- early or sorghum-sudangrass-late. In 2013 cowpea-late had the highest number of leaves per head. In 2014 black oats-early had the highest number of leaves per head.

Head dry weight

In 2013 cowpea-late had higher head dry weight than buckwheat-early, cowpea-early, sorghum-sudangrass-early or sorghum-sudangrass-late (Table 3.5). In 2014 cowpea-early had higher head dry weight than control-late, cowpea-late or sorghum-sudangrass-late.

Discussion and Conclusion

In both years between cover crops and control treatment, cover crops reduced the amount of weeds. This is similar to findings of Creamer and Baldwin, (2000) and Wang et al., (2008b) who also observed weed suppression through the use of cover crops. The study by Creamer and Baldwin, (2000) studied cover crops growing midsummer similar to the current study. Cover crops studied included buckwheat, cowpea, and sorghum-sudangrass all of which suppressed weed growth compared to the control. There is only one cover crop in 2014 that is cowpea which did not reduce weeds when compared to control. With the wide diversity of cover crops available, a good stand of cover crop can be used as a valuable and sustainable weed management tool during a fallow season with a short season cover crop.

Among the cover crops in 2013, cowpea significantly increased soil nitrogen while in 2014 the increase was not significant. This could be attributed to the increased precipitation experienced in 2014 during the duration of the experiment in the field. The additional rainfall in 2014 could have led to enhanced leaching of soil nitrogen. However, the increased amount of nitrogen from cowpea in both years can be attributed to cowpea's ability to fix nitrogen as well as its low carbon to nitrogen ratio (Creamer and Baldwin, 2000).

When comparing cover crops in this study with the control treatment, there is no clear choice to which cover crop provides a clear advantage to the lettuce. There is clearly a trend that the cowpea-early or cowpea-late treatment had higher numerical values in multiple categories specifically head dry weight, head diameter, leaf area, leaves per head and marketable yield. This trend agrees with Wang et al. (2008a) who also saw that there was a benefit from a cowpea cover crop planted before a fall lettuce crop.

Overall sorghum-sudangrass treatment did not have any significant beneficial effect on the lettuce crop. Sorghum-sudangrass consistently trended to have lower yield and head diameter relative to all other treatments. Not one measurement taken on yield, head dry weight, head diameter, leaf area, or leaves per head were statistically higher than the control in the form of a benefit to the following lettuce crop. Wang et al. (2008a) in a similar trial with lettuce, more often saw the same trend where sorghum sudangrass rarely offered a benefit over the control but often detrimentally affected the lettuce crop. This also agrees with Finney et al. (2009) who also observed detrimental effects of sorghum-sudangrass cover crop on a following cabbage crop. Results from our study lead us to conclude that sorghum sudangrass has the potential to detrimentally affect the succeeding crop and growers should be careful while using sorghum sudangrass. There could be two possible explanations for the negative effect of sorghum sudangrass on lettuce. First, there is possibility that sorghum sudangrass, due to the high C:N ratio in its biomass (Creamer and Baldwin, 2000), could have tied up soil nitrogen rendering it unavailable to the lettuce crop (Kuo and Sainju, 1998). Secondly, there are studies that have attributed vegetable yield loss to allelochemical properties from a sorghum-sudangrass cover crop (Finney et al., 2009).

One aspect that was positively influenced by the cowpea cover crop was the harvest date of lettuce. When examining the harvest dates of lettuce across both years, the cowpea-early and cowpea-late treatments were one of the first to be harvested, with the exception of the buckwheat-early and control-early in 2014. This demonstrates a positive influence of cowpea cover crop on lettuce. Lettuce plants in the cowpea treatment spent less time in the field being exposed to weather, insects, or pathogens that could decrease marketable yield. The additional soil nitrogen added by the cowpea cover crop could have contributed to faster growth and overall superior quality. The high amount of soil nitrate and ammonium found in 2013 in the cowpea treatment would explain why cowpea-early and cowpea-late were the first treatments harvested. Similarly, in 2014, cowpea treatment trended to have higher soil nitrate and ammonium when compared to other treatments at the late lettuce planting date and late fall. Nitrogen is one of the key nutrients that affects plant growth and its increased availability can enhance the speed of plant growth (Walker et al. 2001).

With respect to planting time after cover crop soil incorporation, there is no clear pattern between any cover crop that either date is better for plant growth than the other; however, planting date can affect the time to harvest. In 2014 the buckwheat-early and control-early reached optimal growth 5 d ahead of the buckwheat-late or control-late treatment. The extra week of growth due to early planting would have been an advantage before the days got too short in the fall compared to other treatments that were planted eight days later. This factor strengthens the argument that in northern climatic regions like Iowa and the Midwest, planting immediately after cover crop soil incorporation could result in a better quality lettuce crop partially due to the higher number of degree days the crop can use and reduce exposure to pest and diseases. This disagrees with past research by Ackroyd and Ngouajio (2011) who suggests a planting date of 8 days or longer after cover crop soil incorporation. That study was different from our study as it examined the effect of oilseed radish (*Raphanus sativus* var. *oleifera*), oriental mustard (*Brassica juncea*), and yellow mustard (*Sinapis alba*) cover crops, which are known to produce Isothiocyanates that act as biofumigants. Additionally, the study focused on direct seeding of muskmelon (*Cucumis melo* Group *reticulatus*) rather than transplants, as in the case of our study.

Cover crops have been shown to have many advantages when integrated into growing systems. In conclusion, this study observed specific advantages with certain cover crops and planting date of the cash crop after soil incorporation of cover crops. For growers deciding when to plant after the cover crops tested in this study, it appears that planting earlier rather than later will increase the yield and quality of the following vegetable crop. With respect to weed management, cover crops successfully suppressed weeds.

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Table 3.1. Pest management products and dates of application in 2013 and 2014.

Date	Chemical applied	Rate·ac^{-1}
	2013	
23 Aug.	Esfenvalerate[z] 8.4%	0.04 lb
6 Sep.	*Bacillus thuringiensis*[y] 23.7%	1.0 lb
13 Sep.	Pyrethrins[x] 5%, *Bacillus thuringiensis* 23.7%	20.0 oz, 1 lb
27 Sep.	*Bacillus thuringiensis* 23.7%	1.0 lb
10 Oct.	*Bacillus thuringiensis* 23.7%	1.0 lb
	2014	
23 Sep.	Acetamiprid[w] 70%, Novaluron[v] 9.3%	9.9 oz, 29.7 oz
29 Sep.	23.7% *Bacillus thuringiensis*,	3.7 lb, 14.8 oz

[z]Dupont Asana XL (E. I. du Pont de Nemours and Company, Wilmington, DE)

[y]Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351 fermentation solids spores and insecticidal toxins [Dipel DF (Valent Biosciences Corp., Libertyville, lL.)]

[x]PyGanic Crop Protection EC 5.0II (MGK, Minneapolis, MN)

[w]Assail (UPI, King of Prussia, PA)

[v]Rimon 0.83 EC (Chemtura Corporation, Middlebury, CT)

Table 3.2. Weed biomass within cover crop treatments in 2013 and 2014.

Cover Crop	2013 Weed biomass (kg·ha^{-1})			2014 Weed biomass (kg·ha^{-1})		
	Broadleaf	Grass	Total[z]	Broadleaf	Grass	Total
Control	1,290 a[y]	2,000 a	3,300 a	1,100 a	1,310 a	2,410 a
Buckwheat	60 c	200 c	260 c	170 b	610 b	790 b
Cowpea	640 b	1,010 b	1,640 b	590 ab	1,230 a	1,810 a
Black oats	410 bc	770 b	1,180 b	300 b	520 b	820 b
Sorghum-sudangrass	620 b	980 b	1,600 b	350 b	330 b	680 b
Significance	**[x]	***	***	*	**	***

[z]Total represents the combined value of broadleaf and grass weed biomass within each cover crop treatment

[y]Mean separation within column by the least significant difference test ($P \leq 0.05$). Values within each column sharing the same letter are not different.

[x]*, **, ***, significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 3.3. Measurement of chlorophyll content using SPAD meter in 2013 and 2014.

	SPAD[z]	
Cover crop	2013	2014
Control	39.6 a[y]	33.4 b
Buckwheat	40.0 a	34.5 ab
Cowpea	41.2 a	33.0 b
Black oats	40.0 a	35.7 a
Sorghum-sudangrass	37.5 b	35.9 a
Planting date		
Early	40.3 A	33.4 B
Late	38.9 B	35.6 A
Significance		
Cover crop	*[x]	*
Planting date	**	***
Cover crop × planting date	NS	NS

[z]SPAD measurement average of 3 leaves per plant and 6 plants per treatment per replication.

[y]Mean separation within cover and planting date by least significant difference at $P \leq 0.05$. Values within each column sharing the same letter are not different.

[x]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 3.4. Cover crop and planting date effect on transplant health score in 2013 and 2014.

Cover crop/planting date	Health score[z]	
	2013	2014
Control		
Early	2.9 c[y]	4.0 a
Late	3.0 c	3.2 dc
Buckwheat		
Early	2.9 c	3.9 a
Late	3.0 c	3.0 d
Cowpea		
Early	4.0 a	4.0 a
Late	3.4 b	3.7 ab
Black oats		
Early	2.9 c	3.5 bc
Late	3.0 c	3.0 d
Sorghum-sudangrass		
Early	3.0 c	3.1 d
Late	3.0 c	2.9 d
Significance		
Cover crop	***[x]	***
Planting date	*	***
Cover crop × planting date	***	*

[z]Health score rating of transplants assigned on 20 Aug. 2013 and 15 Aug. 2014 using following five point scale: 1= dead, 2= leaf yellowing or lower leaves were drying up, 3= no growth since transplanting, 4= transplant has three to six new leaves, 5= transplant has seven or more new leaves.

[y]Mean separation between treatments within columns by least significant difference test ($P \leq 0.05$). Values within each column sharing the same letter are not different.

[x]*,**,***, significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 3.5. Effect of cover crop and planting date on head dry weight, head diameter, leaf area, and number of leaves of lettuce in 2013 and 2014.

Cover crop/planting date	Head diameter[z] (cm)		Leaf area[y] (cm^2)		Leaves per head[x]		Head dry weight[w]	
	2013	2014	2013	2014	2013	2014	2013	2014
Control								
Early	18.7 cd[v]	24.6 a	2,300 ab	2,300 abc	24.0 b	20.4 cde	11.5 abc	7.8 ab
Late	20.1 bc	20.6 bc	2,200 abc	2,100 abcd	22.3 bc	22.5 bc	11.6 ab	6.0 bc
Buckwheat								
Early	19.1 dc	22.7 ab	2,100 abcde	1,900 cde	22.8 bc	20.8 bcd	10.0 bcd	7.5 abc
Late	19.3 dc	18.4 dc	2,000 bcde	2,000 bcde	20.0 cde	21.0 bcd	10.8 abcd	6.9 abc
Cowpea								
Early	22.5 a	24.9 a	1,600 f	2,500 a	18.5 de	22.6 bc	7.3 e	8.3 a
Late	21.9 ab	22.7 ab	2,400 a	1,700 e	30.5 a	18.1 e	12.1 a	5.7 c
Black oats								
Early	19.1 dc	20.1 c	2,200 abcd	2,300 ab	21.9 bcd	25.9 a	10.9 abcd	7.8 ab
Late	19.0 dc	18.1 de	2,000 cdef	2,100 bcde	21.0 bcde	22.1 bcd	10.3 abcd	6.4 abc
Sorghum-sudangrass								
Early	16.5 e	15.5 f	1,800 def	2,000 bcde	17.8 e	23.1 b	9.5 d	6.7 abc
Late	17.5 de	16.0 ef	1,800 ef	1,800 de	19.8 cde	19.8 de	9.8 dc	5.7 bc
Significance								
Cover crop	***[u]	***	*	NS	*	**	NS	NS
Planting date	NS	***	NS	*	*	**	*	**
Cover crop × planting date	NS	**	**	*	***	**	**	NS

[z]Average head diameter of lettuce plants on 18 Sept. 2013 and 10 Sept. 2014 measured in the field prior to the first harvest.
[y]Average leaf area per head of marketable lettuce plants at time of harvest. Data collected from two heads.
[x]Average leaves per head of marketable lettuce plants only at time of harvest. Data collected from two heads.
[w]Head dry weight of marketable lettuce heads dried in an oven for 3 days at 67°C. Data collected from two heads.
[v]Mean separation between treatments within columns by least significant difference test ($P \leq 0.05$). Values within each column sharing the same letter are not different.
[u] NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 3.6. Cover crop and planting date effect on marketable and non-marketable lettuce yield and head count in 2013 and 2014.

Cover crop/planting time	Marketable [z]				Non-marketable[y]	
	2013		2014		2013	2014
	weight ($kg\cdot ha^{-1}$[x])	number (per ha^{-1}[w])	weight ($kg\cdot ha^{-1}$)	number (per ha^{-1})	weight ($kg\cdot ha^{-1}$)	weight ($kg\cdot ha^{-1}$)
Control						
Early	3,524 abc[v]	17,601 abc	4,609 a	25,875 ab	2,182 ab	738 b
Late	4,174 ab	20,565 ab	4,799 a	22,650 ab	2,160 ab	1,511 b
Buckwheat						
Early	3,366 abc	18,135 abc	1,891 c	18,630 bc	2,309 ab	1,180 b
Late	4,360 ab	22,895 a	3,781 ab	20,010 bc	1,531 bc	1,490 b
Cowpea						
Early	2,854 bc	20,959 ab	5,099 a	28,290 a	1,132 c	518 b
Late	4,683 a	20,328 ab	1,856 c	13,230 cd	2,543 a	1,680 b
Black oats						
Early	3,462 abc	16,839 abc	4,809 a	23,730 ab	2,015 ab	1,221 b
Late	3,002 bc	15,030 bc	2,415 bc	13,455 cd	2,537 a	2,208 ab
Sorghum-sudangrass						
Early	2,074 c	12,465 c	2,108 c	10,650 d	1,707 abc	6,106 a
Late	1,874 c	11,115 c	1,559 c	8,970 d	2,009 ab	2,256 ab
Significance						
Cover crop	NS[u]	*	**	**	NS	NS
Planting date	NS	NS	*	**	NS	NS
Cover crop × planting date	NS	NS	**	*	*	NS

[z]Marketable lettuce has a head approximately 20 cm wide with no cuts, bruises, lesions, or pest damage.
[y]Non-marketable lettuce is a head size less than 20 cm wide and/or with cuts, bruises, lesions, or pest damage
[x]Yield was measured with the lower wrapper leaves removed.
[w]Count per hectare is the number of marketable heads that make up the marketable yield.
[v]Mean separation between treatments within columns was done by least significant difference test ($P \leq 0.05$). Values within each column sharing the same letter are not different.
[u] NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

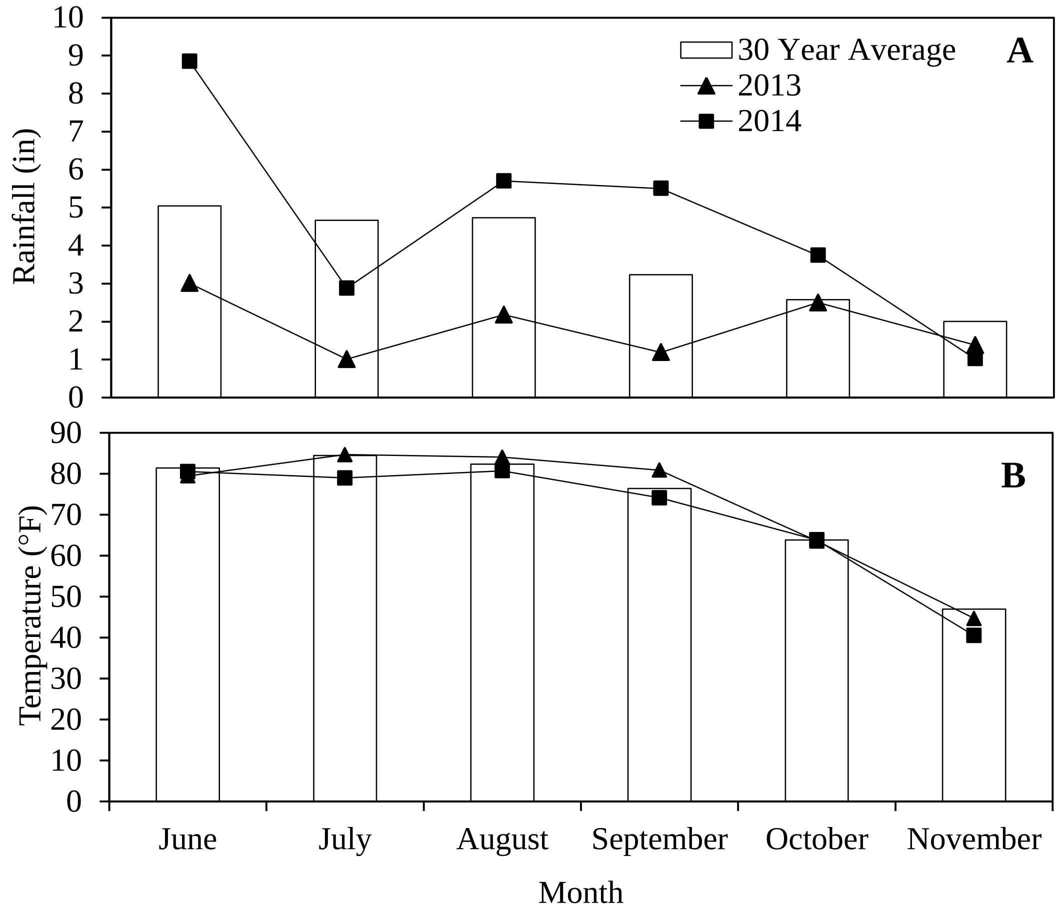

Figure 3.1 Accumulated monthly rainfall (A) and average monthly daytime high temperature (B) in 2013 and 2014 compared with the thirty year average.

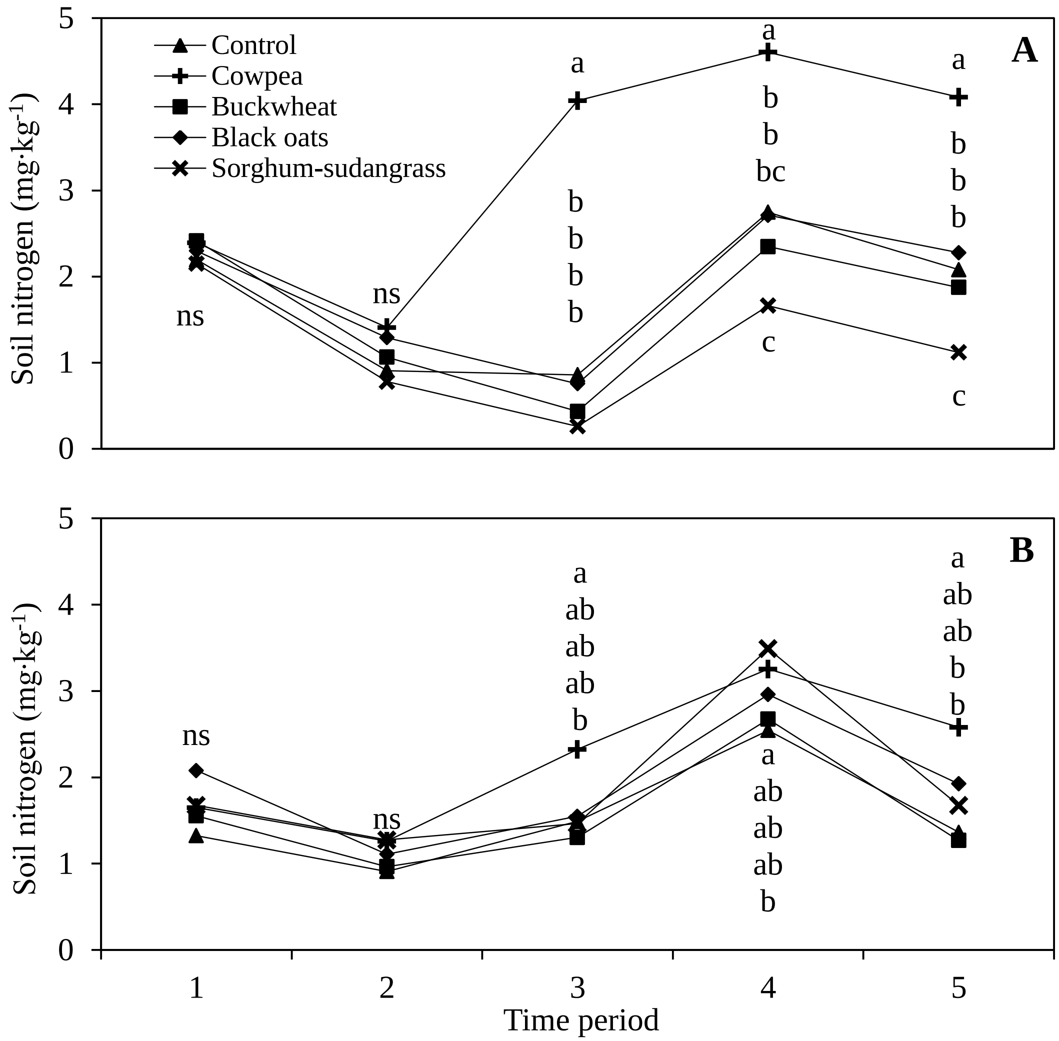

Figure 3.2. Soil nitrogen concentration (nitrate + ammonium) as influenced by cover crop over time in year 2013 (A) and 2014 (B). Mean separation between treatments at each date by least significant difference test (P≤0.05). Treatment dates that are not significant = ns. Time periods represent sampling dates: 1= cover crop seeding, 2= early planting date, 3= late planting date, 4= first lettuce harvest, and 5= late fall (40 d after time 4).

CHAPTER 4. FALL COVER CROP INFLUENCE ON WEED POPULATION DENSITY, SOIL NITROGEN, AND POTATO YIELD

Modified from a paper written for HortTechnology

Raymond Kruse[1], Ajay Nair[1*], and Micheal Owen[2]

Abstract

The growth, development, yield, and quality of the potato crop is largely dependent on production practices and inputs during the growing season but soil management practices undertaken the previous fall can also affect crop performance. This study conducted at the Horticulture Research Station, Iowa State University, Gilbert, IA investigated the effect of fall planted cover crops on spring potato production. The experiment was a split-plot Latin square design with cover crops as the wholeplot and potato cultivars as the subplot factor. Cover crop treatments included crimson clover (*Trifolium incarnatum*), oilseed radish (*Raphanus sativus* var. *oleifera*), cereal rye (*Secale cereale*), or no cover crop (control plot). Potato (*Solanum tuberosum*) cultivars tested included ‘Yukon Gold’ and ‘Red Pontiac’. Data collected included cover crop biomass, weed density, soil nutrient concentration, soil microbial biomass, crop yield and quality parameters. In the early spring cover crops reduced weed populations compared to the control plot. The

[1]Department of Horticulture, Iowa State University, Ames, IA 50010

[2]Department of Agronomy, Iowa State University, Ames, IA 50010

*To whom correspondence should be addressed E-mail nairajay@iastate.edu

effects were not seen once the cover crops were terminated. Among cover crops, oilseed radish and cereal rye showed pronounced effect on suppressing both broadleaf and grass weeds during the cover crop growth period in fall and early part of the potato growing season. Crimson clover increased whereas cereal rye decreased soil nitrogen concentration at the time of cover crop soil incorporation compared to the control plot treatment. Later in the potato growing season, cover crops ceased to have any pronounced effect on soil nitrogen concentration. Leaf chlorophyll content was measured using a SPAD meter and showed no significant difference between cover crop treatments. Soil microbial biomass analyzed in soils collected at the end of the growing season did not show any significant difference among cover crop treatments in both years. Cover crops did not have any effect on final potato yield but yield for ‘Red Pontiac’ was significantly higher than that for ‘Yukon Gold’. There was no effect of cover crops on potato specific gravity; however, ‘Yukon Gold’ had higher specific gravity than ‘Red Pontiac’ potatoes. Overall, the study demonstrates positive effects of cover crops on weed suppression and soil chemical properties. Cover crops did not have any negative effect on potato yield or quality.

Introduction

More and more vegetable growers foresee the importance and relevance of cover crops in their production systems (Hartwig and Ammon, 2002). Cover crops provide multiple benefits ranging from weed suppression, reduced nutrient loss especially nitrate leaching, reduced soil erosion, and improved soil structure, organic matter and fertility (Snapp et al., 2005; Teasdale, 1996). Fall cover crops have been studied extensively within grain crops (Cicek et al., 2015; Kaspar et al., 2012) but given the wide array of vegetables grown, more research is needed on how fall planted cover crops can affect spring vegetable production.

Impact of cover crops has been largely positive on vegetable yield and quality. Studies have shown increased lettuce and onion yield when planted after cover crops (Wang et al., 2008a; Wang et al., 2008b). In other studies cover crops have decreased vegetable yield. Finney et al. (2009) reported reduced cabbage (*Brassica oleracea* var. *capitata*) growth following a sorghum-sudangrass (*Sorghum bicolor ssp. Drummondii*) cover crop.

In northern climatic regions, one of the most widely studied cover crops is cereal rye. Given the ease with which it fits in various production systems and later planting windows required, a lot of information is available on the use of cereal rye. Cover crops such as oilseed radish, clovers, etc. are good candidates for fall planting but they typically need to be planted earlier than cereal rye (Clark, 2007). Vegetable growers have the flexibility to plant these cover crops, in addition to the traditional cover crop of cereal rye, but more information is needed on how these crops will aid in weed suppression, soil nutrient cycling, and affect yield and quality of the vegetable crop.

Campiglia et al. (2009) found that hairy vetch (*Vicia villosa*) and subclover (*Trifolium subterraneum*) increased potato yields compared to an unfertilized control. The yield increase was equal to that of a fertilized control plot. Little et al. (2004) found that cover crops including common oats (*Avena sativa*), white lupin (*Lupinus albus*), and fodder rape (*Brassica napus)* planted before a potato crop had no effects on potato tuber yield, however, when looking at their non-fertilized treatments, negative effects were observed from cover crops on tuber specific gravity compared to the control.

This study investigated the use of three cover crops (cereal rye, crimson clover, or oilseed radish) in potato production. The main objectives of this study were to: (i) evaluate and compare weed suppression capability of cover crops; (ii) evaluate soil nitrogen and microbial biomass in potato production under cover crops; and (iii) quantify potato yield and quality.

Materials and Methods

Site description

The experiment was conducted at the Iowa State University Horticulture Research Station, Gilbert, Iowa, USA. This study consisted of two potato growing seasons, 2014 and 2015, each of which had the cover crop treatments seeded the prior fall. The soil type was Clarion which is fine-loamy, mixed, superactive, mesic Typic Hapludoll with 2 to 6% slopes. At the time of cover crop seeding in 2013 baseline soil nitrogen, phosphorous, and potassium concentrations were 4.6, 15.4, and 82.6 $mg \cdot kg^{-1}$, respectively. In 2014, the baseline soil nitrogen, phosphorous, and potassium concentration were 4.7, 43.9, and 119.8 $mg \cdot kg^{-1}$, respectively. At the time of potato planting soil pH and EC were 6.6 and 0.54 mS/m in 2014 and 6.3 and 0.38 mS/m in 2015, respectively.

Experimental design

The experimental design was a Latin square split-plot design with cover crop as the whole plot factor including: cereal rye (*Secale cereale* ‘Wheeler’), crimson clover (*Trifolium incarnatum*), oilseed radish (*Raphanus sativus* ‘Defender’), or no cover crop (control), and potato cultivar (‘Yukon Gold’ or ‘Red Pontiac’) as the subplot factor. Each whole plot measured 20 ft. by 23 ft. Six potato rows were planted in each whole plot. Potato rows were 18 ft. long and 40 in. apart (center to center). Each end row was a guard row planted into a different cultivar ‘Purple Majesty’ to eliminate cross contamination between cover crop treatments. The middle four rows were planted to two data cultivars that alternated between each other for a total of two data rows per cultivar per plot.

Cover crop seeding and establishment

Soil was roto-tilled using a Terra Force GM 102 rototiller (Terra Force, Inc. Carrollton, TX) twice before cover crop seeding. Cover crops were seeded on 20 and 25 Aug. in 2013 and 2014, respectively. Seeding rates were 60, 30, and 15 $lb \cdot ac^{-1}$ of cereal rye, crimson clover, and oilseed radish, respectively. Cover crops were seeded using a 22 in. wide Scotts Turf Builder Classic Drop Spreader (The Scotts Company LLC., Marysville, OH) in 2013 and a 42 inch variable rate Gandy drop spreader (Anertec & Gandy Company, Owatonna, MN) in 2014. In 2013, immediately after seeding, cover crops were incorporated using a drag harrow and then overhead irrigated. Two weeks later the plot was once again irrigated. In 2014, cover crops seeds were incorporated using a rotary tiller to a maximum depth of 2 in. The soil was then packed with a cultipacker to ensure good seed-to-soil contact. No supplemental irrigation was provided in 2014.

Cover crop biomass

Cover crop biomass for crimson clover and oilseed radish was collected on 16 Oct. and 27 Oct. in 2013 and 2014, respectively. Weed biomass was also collected from the control plot on those dates. For cereal rye, biomass was collected on 16 Apr. and 31 March in 2014 and 2015, respectively. Due to earliness of the season no live weeds were present in the cereal rye plots at the time of biomass sampling. Biomass samples were collected using 50 × 50 cm quadrats that were placed in two representative areas of the cover crop treatment in each replication. Both above and below ground biomass of cover crops and weeds were collected and plants were counted. Weeds were separated into broadleaf and grass categories. Biomass samples were dried in a forced-air oven at 67°C until a constant weight.

Plot establishment and planting

Cover crop and control plots were tilled on 19 Apr. and 30 Mar. in 2014 and 2015, respectively. Plots were again tilled for a final field preparation on 7 May and 23 April in 2014 and 2015, respectively. Fertilizer was applied before tilling and will be discussed later. Furrows, 40 in apart, were constructed four to six in. deep. Tubers were placed in the furrow nine in. apart and covered with soil to create a six to eight in. mound of soil over the tubers. Potato cultivars in this study, ‘Yukon Gold’ and ‘Red Pontiac’, were selected based on common fresh market cultivars grown in Iowa and the North Central region. In 2014 seed tubers were cut into pieces that averaged 2 oz. and planted the same day. Any tuber that was less than 2 oz. in weight was not cut. The first planting of potatoes (7 May, 2014) failed due to the occurrence of soft rot caused by (*Pectobacterium carotovorum).* Many tubers were dug to evaluate the infestation. An estimated 90% of the seed pieces failed to emerge and rotted in the ground. Only the cut tubers were infected with the pathogen. A second planting took place on 11 June 2014. For that planting to eliminate potential disease occurrence and spread, cutting knives were dipped in 190 proof ethyl alcohol between every five cuts. Cut tubers were then laid on a bench top at 68°F ambient temperature no more than two pieces deep to promote callus formation before planting. The same approach for the second planting in 2014 was also taken in 2015.

Fertilization

Potatoes were fertilized using urea, monoammonium phosphate, and potassium chloride. The final rate applied in both years was 115, 22, and 42 $lbs \cdot ac^{-1}$ of nitrogen, phosphorous, and potassium with the exception of the potassium which was applied at the rate of 83 $lbs \cdot ac^{-1}$ in 2015. The nitrogen application was split over two application dates, with the first application of 45 $lbs \cdot ac^{-1}$ at planting and remaining 70 $lbs \cdot ac^{-1}$ at tuber bulking.

Weed count and biomass

Weed counts were tracked throughout the potato growing season from cover crop termination until potato harvest. Counts were recorded at specific time periods before field operations were performed. These time periods include: cover crop termination, first cultivation, initiation of tuber bulking, and final harvest. These events coincided with the following dates in 2014: 19 Apr., 8 July, 31 July, and 8 Oct. In 2015 weed counts were collected on these dates: 31 Mar., 2 June, 18 June, and 14 Aug. Weed counts were collected by laying two 0.5 m^2 quadrats in each whole plot treatment between potato rows. An analysis of weed biomass was done on the weed counts measured at first cultivation. Weeds were categorized into broadleaf and grass categories and placed in a forced air oven at 67°C until a constant weight.

Weed management

At the time of cover crop termination the initial flush of weeds was managed by tillage. Later during the growing season weeds were managed using a one-row cultivator with 10 in. sweeps that cultivated within 5 in. of the potato plants in the rows. After cultivation a quick rouging with a hand hoe was done to further remove any existing weeds within potato rows. Potatoes were monitored from this day forward to identify tuber bulking initiation so that the future cultivation did not injure any developing potatoes. Potatoes were again cultivated on 31 July and 18 June in 2014 and 2015, respectively. After cultivation, potato rows were hilled using a disk to mound the soil around the potatoes to a height of four to six in. above the original field grade.

Insect management

A threshold of three adult potato leafhoppers (*Empoasca fabae*) per plant was established. On 5 Aug. 2014 up to 10 insects per plant were observed which were managed by spraying Acetamiprid (Assail 30 SG®, United Phosphorous Inc., King of Prussia, PA) at the rate of 4 $oz \cdot ac^{-1}$. The field was again sprayed on 14 Aug 2014 with Carbaryl (Sevin XLR Plus, Tessenderlo Kerley, Inc., Phoenix, AZ) at the rate of 2 $qt \cdot ac^{-1}$ along with the tank conditioner Phosphatidylcholine, methylacetic acid and alkyl polyoxyethylene ether (LI – 700, Loveland Products Inc., Greely, CO) that served as an acidifier that was applied at the rate of 4 oz. per 100 gallons of solution applied.

Leaf chlorophyll content

Potato leaf chlorophyll was measured using a SPAD-502Plus meter (Konica Minolta Sensing Americas, Inc., Ramsey, NJ). Measurements were taken on 22 Aug. and 9 July in 2014 and 2015, respectively. The leaf chosen for measurement was the first fully opened compound leaf from the top with an extended petiole from the main stem. Three readings were taken from the outermost three leaflets. These three readings were averaged and recorded as a single data point. Data was collected from a total of six plants within each subplot (cultivar) treatment.

Soil nutrient sampling and analysis

Soil samples were collected for soil analysis at specific time periods throughout the course of the experiment. Four baseline soil samples were collected at the time of cover crop seeding on 11 Aug. and 29 Aug. in 2013 and 2014, respectively. Samples were collected from a six in. depth. Soil samples were taken on 16 April (cover crop termination), 20 June (after planting), 31 July (tuber initatiation/bulking), and 7 Oct. (potato harvest) in 2014. Similarly, soil samples were collected on 30 March (cover crop termination), 30 Apr. (after planting), 25 June (tuber initatiation/bulking), and 14 Aug. (potato harvest) in 2015. Soil samples were analyzed for N, P, and K concentrations. Soil N was extracted using 2 N potassium chloride solution. Extracts were analyzed on a Lachat QuikChem 8500 Series 2 (Hach Company, Loveland, CO) for nitrate and ammonium content. For P and K, soils were extracted using Mehlich III solution. Extracts were analyzed using an ICP Thermo Scientific ICAP6300 Redial analyzer (Thermo Fisher Scientific, Waltham, Ma).

Harvest and quality assessment

Potatoes were harvested on 8 Oct. and 14 Aug. in 2014 and 2015, respectively. Potatoes were dug using a one row 15 in. high-wing furrowing blade (Wiese Industries, Perry, IA) mounted on a 3 point tractor frame. Following harvest potatoes were stored at room temperature (65°F) for one to two weeks until grading. Potatoes were graded following the United States Standards for Grades of Potatoes (United States Department of Agriculture, 1997). Grade A consisted of tubers that were 1.875 in. or larger in diamater, followed by Grade B tubers that were 1.875 in. to 0.75 in. in diameter. From each A and B grade, before weighing any cosmetically defected potatoes were removed and counted as one non-marketable measurement. Non-marketable tubers included tubers that had cracking, rotting, excessive scab, insect damage, or were misshapen. Following grading, tuber specific gravity was measured by pulling 3.63 kg of Grade A potatoes from each treatment and using a potato hydrometer (Snack Foods Association, Arlington, VA).

Soil microbial biomass

Soil microbial biomass samples were taken within data rows from six in. depth at the time of harvest. Samples were immediately transported to the lab in a cooler. Within 48 h, samples were processed and extracted using the Chloroform Fumigation Extraction Method (Vance, 1987) with minor modifications. Extracts were frozen at -20°C and later analyzed using a Torch Combustion TOC/TN Analyzer (Teledyne Tekmar, Mason, OH).

Data analysis

Data sets were analyzed with SAS statistical software version 9.3 (SAS Inc. Cary, NC). The PROC MIXED method was used and mean separation was done by the Least Significant Difference ($P \leq 0.05$) method. Data was run as a Latin square design with a replication and column value for each set of data. Replication and columns were treated as random factors nested within year. Data from the soil nitrogen, phosphorous, potassium, and weed count were run as a repeated measure. If year × treatment interactions existed the data were run separately by year, otherwise data were combined.

Results

Weather

Air temperatures in the 2013 were above normal when compared to the 30 year average in August and September for cover crop growth as seen in Fig. 4.1 (Iowa

Environmental Mesonet, 2015). Air temperatures in 2014 were below the 30 year average for cover crop growth. During the potato growing season monthly precipitation followed about the same pattern in both years with June having lots of precipitation and tapering off in July.

Cover crop biomass

For cover crop seeded in 2013, biomass ranged from 423 $kg \cdot ha^{-1}$ for crimson clover to 5,052 $kg \cdot ha^{-1}$ for oilseed radish (Table 4.1). Oilseed radish produced significantly higher biomass than crimson clover but it was not significantly different than cereal rye (2,326 $kg \cdot ha^{-1}$). For cover crops seeded in 2014, the highest amount of biomass was produced by cereal rye (8,392 $kg \cdot ha^{-1}$) followed by oilseed radish (5,364 $kg \cdot ha^{-1}$). Crimson clover had the lowest biomass of 3,050 $kg \cdot ha^{-1}$. There was no difference in cover crop density ($count \cdot ha^{-1}$) in 2013 but in 2014, crimson clover had the highest density.

Weed biomass and count in cover crops

In 2013, broadleaf weed biomass was higher in control and crimson clover treatments as compared to oilseed radish or cereal rye (Table 4.1). In 2014 only cereal rye suppressed weeds. Grass weed biomass for 2013 followed the same trend as broadleaf biomass in 2013 with control and crimson clover treatments having higher weed biomass than oilseed radish or cereal rye. No effect of cover crop on grass weed biomass was observed in 2014. Among the broadleaf and grass weed populations a clear pattern is seen. Cereal Rye and Oilseed Radish suppressed weeds compared to the control.

Soil nutrient concentration

Data from soil nitrogen concentration was combined because no treatment by year interaction existed. At the time of cover crop termination soil nitrogen concentration was highest in the crimson clover treatment when compared to the control or cereal rye (Table 4.2). Cereal rye plots had the lowest soil nitrogen of all the treatments. At the time of potato planting no statistically significant differences were measured among cover crop treatments. The control treatment had a statistically similar amount of soil nitrogen as crimson clover and oilseed radish, but had lower soil nitrogen compared to cereal rye. For the rest of the sampling periods (tuber initiation/bulking and harvest) differences in soil nitrogen concentrations were non-significant. Extractable soil phosphorous and potassium concentrations were not significant among any treatments at any given time in either year.

Weed populations and biomass during the potato growing season

Predominant broadleaf weeds during the study were common lambsquarter (*Chenopodium album*), common purslane (*Portulaca oleracea*), Pennsylvania smartweed (*Polygonum pensylvanicum)*, redroot pigweed (*Amaranthus retroflexus*), and tall waterhemp (*Amaranthus tuberculatus*). Predominant grass weeds were green foxtail (*Setaria viridis*), giant foxtail (*Setaria faberi*), large crabgrass (*Digitaria sanguinalis*), witchgrass (*Panicum capillare*), and yellow foxtail (*Setaria pumila*). During the growing season, for both 2014 and 2015, the only difference in weed count was observed at the time of cover crop termination. Cereal rye and oilseed radish had the lowest weed counts compared to control and crimson clover treatments (Table 4.3). An additional measurement of weed biomass was taken at cultivation in both years. During the 2014 growing season, broadleaf weed biomass was lowest in the oilseed radish treatment compared to all other treatment. There were no significant treatment differences in broadleaf weed biomass in 2015. Similarly no treatment differences could be detected in grass weed biomass in 2014 and 2015.

Microbial biomass

No differences were observed in soil microbial biomass between any cover crop treatment in either year (data not shown).

Chlorophyll content, potato yield, and quality

Chlorophyll data were combined for both years because there was no year by treatment interaction (Table 4.4). No treatment differences in SPAD readings existed for cover crop treatments; however, differences were significant at the subplot (cultivar) level. ‘Red Pontiac’ cultivar had significantly higher SPAD values as compared to ‘Yukon Gold’. Potato yield and quality data were combined for both years as there was no year by treatment interaction. There were no cover crop treatment effects either on Grade A, Grade B, or non-marketable potatoes. Potato specific gravity followed the same pattern. There were significant differences between cultivars for yield with ‘Red Pontiac’ consistently showing higher values, except in the case of specific gravity where ‘Yukon Gold’ had a significantly higher specific gravity than ‘Red Pontiac’.

Discussion and Conclusion

Cover crops yielded higher biomass in the second year. This could be attributed to better emergence of cover crops as well as optimal growing conditions during the fall of 2014. For example, in the case of crimson clover, the optimum germination temperature range for crimson clover is between 50 and 77°F (Butler et al., 2014). The average high temperature 14 d following cover crop seeding was 89°F in fall 2013 as compared to 81°F in fall 2014 (Iowa Environmental Mesonet, 2015). The cooler weather in the second year may have provided a better growing environment for the cool-season cover crops tested in this study. Similar effects of decreasing temperature have had positive influences on the productivity of oats, which is also a cool-season crop (Saastamoinen, 1998). Another factor that could have contributed to the increased cover crop biomass in 2013 compared to 2014 is the higher amount of phosphorous and potassium in the soil at the time of cover crop seeding in 2014. Soil nitrogen levels at the time of cover crop seeding are most likely not a contributing factor for the differences seen in cover crop biomass.

Oilseed radish had an interesting biomass trend when comparing cover crop biomass and stand count. Cover crop stand for oilseed radish nearly doubled in 2014 compared to 2013, but this did not result in a significant increase in biomass compared to 2013. Oilseed radish biomass increased only by 6% when stand count doubled. This suggests that oilseed radish may perform optimally under a wider range of planting densities or air temperatures compared to the other cover crops tested. However in the case of cereal rye, cover crop biomass increased by 260% when the stand count doubled using the same cultivar. The differences found in this study between oilseed radish and cereal rye, could be attributed to differences in seed size, seed mass, and seeding rate that have profound impact on the performance of plants. Variations in seed size among cultivars and among seed lots of the same cultivar can lead to differences in biomass (Ngouajio, 2009). In a study conducted with oilseed radish, total biomass decreased from

4.2 to 2.5 $T{\cdot}ha^{-1}$ for ‘Defender’ and from 4.1 to 3.3 $T{\cdot}ha^{-1}$ for ‘Daikon’ when the seeding rated increased from 222,208 to 444,416 $seeds{\cdot}ac^{-1}$ (Ngouajio, 2009). For Daikon the decline in biomass with increasing plant population was less dramatic suggesting a greater resilience to intraspecific competition, likely due to larger seed mass (Ngouajio, 2009).

Effects of cover crop treatment on weed population were evident only at the beginning of the potato growing season. At the time of cover crop termination, all cover crops tested in this study provided significant weed suppression compared to the control. A number of cover crop studies have shown weed suppression properties of cover crops (Lawley et al., 2012; Snapp et al., 2005). In the current study cereal rye and oilseed radish provided higher weed suppression with lesser suppression by crimson clover. This could be attributed to the amount of biomass produced by the cover crops (Ngouajio and Mennan, 2005). The increased biomass resulted in shading of the soil and thus a less favorable environment for the weeds to germinate and establish. Small-seeded annual weed species with a light requirement for germination are most sensitive to cover crop residues (Teasdale, 1996). Campiglia et al. (2009) observed that rapeseed (*Brassica napus*) which is in the same family as oilseed radish provided weed suppression in a potato production system compared to a weedy fallow plot. Contrary to our study Campiglia et al. (2009) observed this effect at the end of the growing season. Other studies found no significant effect of cereal rye or oilseed radish cover crop biomass on annual weed populations. In a study conducted by O’Reilly et al. (2011) in sweetcorn there was no weed suppression due to planting an oilseed radish crop before the sweetcorn. On the other hand, a study investigating the use of forage radish (*Raphanus* *sativus*) cover crop observed a high level of early spring weed suppression in plots where forage radish grew in the fall regardless whether residues were left in place or removed (Lawley et al., 2012). The primary mechanism for weed suppression reported by that study was the early and competitive fall growth of forage radish. Results in the current study are consistent with findings from Lawley et al. (2012) in which weed suppression was attributed to a high amount of cover crop biomass.

Microbial biomass carbon was not influenced by the treatments in either year. It is difficult to observe changes or differences in soil microbial biomass carbon brought by cover crop interventions in short-duration studies (Tillman et al., 2015). Even long-term studies similar to Mbuthia et al. (2015) investigating the long term effects of cover crops on microbial biomass carbon and nitrogen did not find any difference in soil microbial biomass carbon between cover crops that included a grass and legume compared to a control with no cover crops. The excessive soil disturbance during the growing season could be a confounding factor that diminished any results we could have seen. An alternative would be to analyze for soil microbial biomass carbon earlier in the season when the cover crops have not decomposed as much in the field with incorporation.

Differences in soil nitrogen concentration were observed only at cover crop termination and at potato planting time. Soil nitrogen concentration was higher in the crimson clover treatment as compared to control and cereal rye treatments at the time of cover crop termination. This could be due to the fact that crimson clover is a legume and has the capability to fix atmospheric nitrogen (Peoples et al., 2014). The low levels of soil nitrogen seen in the cereal rye treatment could be explained by the ability of cereal rye to scavenge nitrogen and use it for biomass production (Kaspar et al., 2012). At the time of potato planting the current study showed higher soil nitrogen concentration in the cereal rye treatment compared to control. One possible conclusion is that cereal rye biomass is decomposing and nitrogen mineralization is occurring. This conclusion is not what we were predicting due to numerous studies stating otherwise. In a controlled environment soil incubation study by Kuo and Sainju, (1998) on nitrogen mineralization of soils amended with rye biomass, soil mineralization of nitrogen to levels equal to the control did not occur until after 20 weeks of incorporation. Ngouajio and Mennan (2005) also stated that nitrogen immobilization occurs after rye cover crop termination. Outside of our predictions Ort et al. (2013) and Hoorman et al.(2009) state that when cereal rye growth is not developed in the spring the carbon to nitrogen ratio of the biomass is small, which in turn favors nitrogen mineralization after termination. Throughout the rest of the season no differences in soil nitrogen were seen among the treatments which agrees with Kuo et al. (1997). This indicates that even though early effects can be seen on soil nitrogen in the field that the effects from the cover crops is short lived and will not be seen throughout the entire season.

Cover crops had no effect on either soil extractable phosphorous or potassium. A study conducted by Kamh et al. (1999) reported that white lupin increased the uptake of phosphorous in wheat resulting in increased growth. However, the soil conditions in which this was observed were very different (acid luvisol low in available phosphorous) from the conditions seen in the Midwest.

Results show no positive or negative effect of cover crops on leaf chlorophyll content in potatoes. Xiong et al. (2015) demonstrated that leaf nitrogen content per unit area has a strong relationship with SPAD readings. (Campiglia et al., 2014) found a strong relationship in SPAD readings of pepper in relation to soil nitrate nitrogen following cover crops. It was found that the hairy vetch cover crop increased soil nitrate nitrogen which in turn increased the pepper leaf SPAD readings. For this reason SPAD readings were taken later in the season to see if the cover crops affected the nitrogen content of the leaves during tuber bulking. Since no differences in SPAD meter readings were observed among treatments the reasoning that the late fall cover crops studied had no late-season effect on the potato crop leaf nitrogen amounts is supported.

Cover crops had no effect on potato yield or quality (specific gravity). Similarly, Little et al. (2004) observed no cover crop influence on potato yield, however, they reported reduced specific gravity in potatoes grown in the cover crop plot . Based on results from the current study, it is suggested that fall-planted cover crops that are terminated in the early spring do not have long-term residual effects on the following potato crop yield. In this study 'Yukon Gold' had lower yields than 'Red Pontiac' but the specific gravity was higher for 'Yukon Gold'. Although interesting, the higher specific gravity does not increase the value of 'Yukon Gold' potatoes because this cultivar is normally used for fresh market or table use and not for processing, where specific gravity is a critical factor.

Even though no yield or quality improvement in potato production was observed through the use of cereal rye, crimson clover, or oilseed radish cover crops, no yield decline was seen either by adding a cover crop to the crop rotation. Cover crops can provide multiple benefits ranging from reduced soil erosion (Corak et al., 1991), increased weed suppression (Teasdale, 1996), increased organic matter and fertility (Snapp et al., 2005), reduced nutrient loss especially nitrate leaching (Kaspar et al., 2012). Thus, integration of fall-planted cover crops for spring potato production could be used as a tool to derive various environmental benefits without any reduction in potato yields the following year.

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Table 4.1. Cover crop biomass and influence on weed biomass and stand count at the Iowa State University Horticulture Research Station, Gilbert, IA, in fall of 2013 and 2014.[z]

	Cover crop biomass ($kg \cdot ha^{-1}$)		Cover crop stand count per ha (millions)		Broadleaf weed biomass ($kg \cdot ha^{-1}$)[y]		Grass weed biomass ($kg \cdot ha^{-1}$)[x]		Total weed number per hectare (million)[w]	
Cover crop treatment	2013	2014	2013	2014	2013	2014	2013	2014	Broadleaf	Grass
Control	-----	------	------	-----	2,400 a	459.0 a	52 a	40	1.950 a	0.220 a
Crimson cover	423 b[v]	3,050 c	0.985	3.120 a	2,218 a	253.0 ab	65 a	12	1.968 a	0.178 a
Oilseed radish	5,052 a	5,364 b	1.040	1.995 b	210 b	0.5 ab	2 b	1	0.450 b	0.058 b
Cereal rye[u]	2,326 ab	8,392 a	1.030	1.965 b	302 b	0.0 b	0 b	0	0.313 b	0.000 b
Significance										
Treatment	*[u]	**	NS	*	***	*	*	NS	***	**
Treatment × year	**	**	*	*	***	***	NS	NS	NS	NS

[z]Measurements in this table for the control, crimson clover, and oilseed radish treatments were taken on 16 Oct. 2013 and 27 Oct. 2014. Measurements in this table for the cereal rye treatment were taken on 16 Apr. 2014 and 31 Mar. 2015.

[y]Values represent broadleaf weed biomass measurements in the growing cover crops at the time of cover crop biomass sampling.

[x]Values represent grass weed biomass measurements in the growing cover crops at the time of cover crop biomass sampling.

[w]Values represent the weed counts of broadleaf weeds and grass weeds at the time of cover crop sampling.

[v]Mean separation within columns was done by least significant difference test ($P \leq .05$). Values within each column sharing the same letter are not different.

[u]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 4.2. Soil nitrogen, phosphorous, and potassium at the Iowa State University Horticulture Research Station, Gilbert, IA, in 2014 and 2015.

	Soil nitrogen ($mg\cdot kg^{-1}$)				Soil Phosphorus ($mg\cdot kg^{-1}$)				Soil Potassium ($mg\cdot kg^{-1}$)			
Treatment	Time 1[z]	Time 2	Time 3	Time 4	Time 1	Time 2	Time 3	Time 4	Time 1	Time 2	Time 3	Time 4
Control	2.3 b[y]	3.9 b	6.2	1.9	39.9[x]	55.9	46.8	35.7	127.8	185.0	129.1	80.3
Crimson rlover	3.0 a	5.3 ab	5.9	1.8	42.8	56.3	50.5	39.2	127.3	198.0	143.6	84.4
Oilseed radish	2.5 ab	4.9 ab	4.7	1.9	32.8	49.1	39.8	32.2	163.8	243.9	136.5	95.2
Cereal rye	1.7 c	6.3 a	4.5	1.8	34.4	54.5	45.0	35.9	124.5	200.3	154.8	94.2
Significance												
Treatment	***[x]	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatment × year	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Time 1,2,3,4 representing soil nitrogen phosphorous and potassium in $mg\cdot kg^{-1}$ for soil samples taken at cover crop termination, potato planting, initiation of tuber bulking, and harvest respectively.

[y] Mean separation within columns was done by least significant difference test ($P\leq.05$). Values within each column sharing the same letter are not different.

[x] NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 4.3. Weed count over time and weed biomass at cultivation in the potato crop at the Iowa State University Horticulture Research Station, Gilbert, IA, in 2014 and 2015.

Cover crop treatments	Weed count per ha (×100, 000)				Broadleaf weed biomass at cultivation ($kg \cdot ha^{-1}$)[z]		Grass weed biomass at cultivation ($kg \cdot ha^{-1}$)[y]	
	Cover crop Termination	Potato Cultivation	Tuber bulking	Harvest	2014	2015	2014	2015
Control	5.46 a[x]	82.68	39.35	11.93	579 a	73	16	36
Crimson clover	3.10 b	91.58	39.13	8.00	590 a	66	31	47
Oilseed radish	0.06 c	72.42	57.28	8.10	231 b	87	19	27
Cereal Rye	0.50 c	85.20	50.22	12.10	537 a	78	29	22
Significance								
Treatment	***[w]	NS	NS	NS	*	NS	NS	NS
Treatment × year	NS	NS	NS	NS	**	**	NS	NS

[z]Broadleaf weed biomass at cultivation on 8 July 2014 and 2 June 2015.

[y]Grass weed biomass at cultivation on 8 July 2014 and 2 June 2015.

[x]Mean separation within columns was done by least significant difference test ($P \leq .05$). Values within each column sharing the same letter are not different.

[w]NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively, based on least significant difference test.

Table 4.4. Effect of cover crops and potato cultivar on chlorophyll content, potato marketable and non-marketable yield, and specific gravity at the Iowa State University Horticulture Research Station, Gilbert, IA, in 2014 and 2015.

Treatments	SPAD[z]	Grade A[y]		Grade B [x]		Non-marketable[w]		Specific Gravity[v]
		kg·ha^{-1}	ct·ha^{-1}	kg·ha^{-1}	ct·ha^{-1}	kg·ha^{-1}	ct·ha^{-1}	
Control	42.0	16,792	100,751	1,955	47,828	6,405	47,756	1.071
Crimson clover	43.1	17,509	106,456	1,938	46,088	6,835	45,693	1.071
Oilseed radish	42.2	17,635	103,693	2,009	50,573	6,387	37,297	1.071
Cereal rye	43.4	17,348	102,814	1,794	44,689	6,189	36,024	1.070
Cultivar								
Gold	39.2 b[u]	9,508 b	67,221 b	1,381 b	33,440 b	1,094 b	7,320 b	1.076 a
Red	46.2 a	25,134 a	139,627 a	2,476 a	61,122 a	11,661 a	76,065 a	1.066 b
Significance								
Treatment	NS [t]	NS	NS	NS	NS	NS	NS	NS
Cultivar	***	***	***	***	***	***	***	***
Treatment × cultivar	NS	NS	NS	NS	NS	NS	NS	NS

[z]Chlorophyll estimation as assigned by the SPAD meter. The higher the rating the more chlorophyll that is present in the leaf.
[y]Grade A included potatoes larger than 1.875 in diameter.
[x]Grade B included potatoes with diameter between 1.875 in. to 0.75 in.
[w]Non-marketable potatoes included potatoes that had cracking, rotting, excessive scab, insect damage, or were misshapen.
[v]Specific gravity was quantified using a potato hydrometer with 3.63 kg of Grade A potatoes from each treatment.
[u]Mean separation within columns between cultivars was done by least significant difference test ($P \leq .05$). Values within each column sharing the same letter are not different.
[t]NS, *** Nonsignificant or significant at $P \leq 0.001$, respectively, based on least significant difference test.

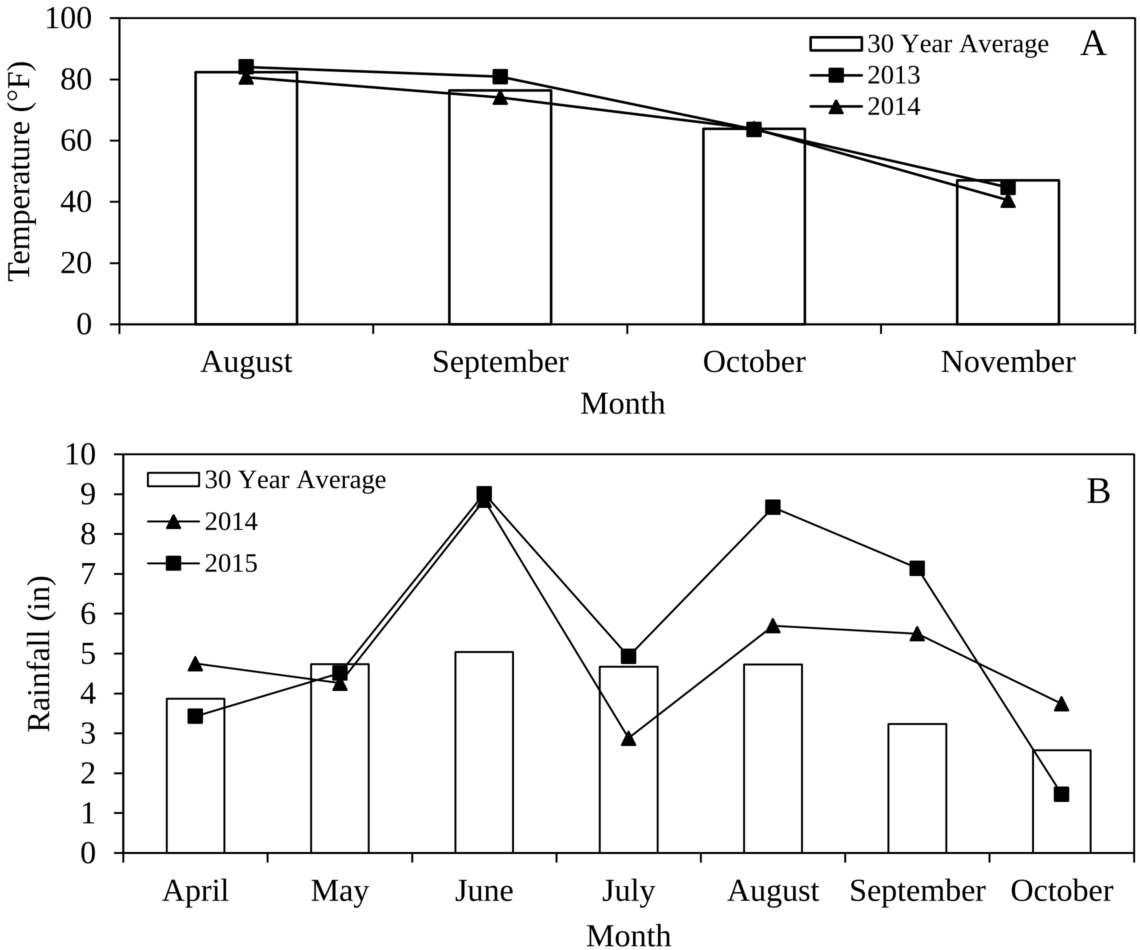

Figure 4.1 Average monthly daytime high temperature (A) in 2013 and 2014 compared with the thirty year average. Accumulated monthly rainfall (B) in 2014 and 2015 compared with the 30 year average.

CHAPTER 4. CONCLUSIONS

Among the three experiments reported above some common trends occur from cover crop use. Cover crops can suppress weeds while growing during a fallow season. No common factor among the cover crops predicts which cover crop would provide the most weed suppression. Cover crop biomass was measured to see if any trends were observed in relation to weed suppression. Ngouajio and Mennan, (2005) state that "Generally weed suppression is correlated with biomass production of the cover crop." However this was not to be the case in the current studies. When looking at the biomass and weed suppression data from chapter one and chapter two, respectively, the cover crop that had the most weed suppression (buckwheat) did not have the highest biomass. The potato study agrees with Ngouajio and Mennan's findings, (2005) in that the best weed suppression in the cover crops occurred in the highest biomass producing cover crops. In conclusion, although cover crop biomass can be an indicator of weed suppression it is not the only measure of weed suppression in a growing cover crop.

Nitrogen fixation by legumes is one common environmental benefit observed among all the experiments. Evidence of increased nitrate concentration is seen in data presented in all three experiments. This proof can be seen in chapter one with soil nitrate concentration, in chapter two with soil nitrogen, and in chapter three with soil nitrogen early in the season. The ability of the legumes used in the study to fix nitrogen is a positive benefit for farmers because they can reduce the amount of additional synthetic fertilizers they apply to achieve healthy yields. However, a common drawback observed among the legumes in these studies is that weed suppression is not as high as other treatments in the experiments. This can be seen in chapter two as well as chapter three.

The ability of legumes to fix nitrogen is an added environmental benefit to using a legume cover crop however drawbacks may exist since weed suppression may not be as good as with other cover crop choices.

A major concern for growers is how the cover crop will affect the yield of the vegetable crop planted after the cover crop. In the cabbage and lettuce experiments cowpea demonstrated benefits to the following crop, such as increased yield in cabbage and earlier date of maturity seen in lettuce. More often there were inconsistent effects of the cover crops among most treatments on the following vegetable yield. These treatments included: buckwheat, crimson clover, black oats, oilseed radish, and rye. With this in mind it is suggested that these cover crops have no effects on the following vegetable yields under the conditions studied. The one cover crop that displayed detrimental effects on the following vegetable crop was sorghum-sudangrass which for lettuce had lower values compared to the other cover crop treatments for health and yield of the vegetable crop. Though the values may not have always been statistically lower, the trend among treatments with sorghum-sudangrass having lower numerical values is an important point.

Planting date of the transplants was investigated in chapters one and two. Inconsistent effects were seen on the following vegetable crops in relation to planting date. In chapter two the early planting date as a trend provided evidence that the early planting date (planting immediately after cover crop termination) was a better for the lettuce crop. This included either increased yields or decreased time to maturity as seen in the lettuce crops.

In the potato experiment the cover crops did not provide any long-term effects that resulted in an increase in the potato crop yield. Differences in soil nitrogen and weed populations were seen in the early season but these small effects did not result in any difference in yield. Oilseed radish may provide a weed biomass suppressive effect later into the growing season but this was only seen one year.

In all three experiments cover crops were successfully integrated into Iowa vegetable production systems. It was demonstrated that cover crops can suppress weeds during the cover crop growing season. Effects were seen on soil nitrogen left over in the soil from legume cover crops. All these factors provided evidence that certain cover crops can benefit a following crop of vegetables.

Some questions have surfaced throughout the course of the three projects. These are posted as potential topics for future research with cover crops.

1. Can equal or greater vegetable yields be achieved if high amounts of additional synthetic nitrogen are applied after a sorghum-sudangrass cover crop?

2. Can effects from fall cover crops be seen on early-planted short-season crops such as lettuce instead of potatoes?

3. Can the planting date after a cover crop is terminated, affect other vegetables such as carrots, common beans, or sweet corn?

Literature Cited

Ngouajio, M. and H. Mennan. 2005. Weed populations and pickling cucumber (Cucumis sativus) yield under summer and winter cover crop systems. Crop Prot. 24:521–526. doi:10.1016/j.cropro.2004.10.004